63-3-2

ALLIS-CHALMERS

ENGINEERING RESEARCH STUDY OF
FUEL CELL POWER PACK

PHASE II REPORT

ALLIS-CHALMERS MANUFACTURING COMPANY
MILWAUKEE 1, WISCONSIN

Contract No. DA-49-186-502-ORD-1057

Report Period: 1 July 1962 to 31 January 1963

28 February 1963

Harry Diamond Laboratories
Ordnance Corps
Washington 25, D. C.

TABLE OF CONTENTS

TABLE OF CONTENTS

1.0 ABSTRACT

A hydrogen-oxygen 1.5 KW fuel cell power pack was built during Phase I of this contract, utilizing the fuel cell state of the art at the initiation of the contract. An evaluation of the power pack was made during Phase II, with respect to operational characteristics and operational life as influenced by environmental and operational conditions. Material and energy balances were made on the power pack. The purpose of the evaluation was to isolate and define system engineering research problems.

Results of the study are presented.

2.0 FORWARD

This is the Phase II report on the Engineering Research Study of A Fuel Cell Power Pack. The report was prepared by the Space and Defense Sciences Department, Research Division of Allis-Chalmers Manufacturing Company and is submitted as part of the contract requirement under Harry Diamond Laboratories Contract No. DA-49-186-502-ORD-1057. Mr. N. Kaplan is the technical supervisor for Harry Diamond Laboratories.

This report covers the work performed in Phase II from 1 July 1962 to 1 February 1963.

The project is supervised by Mr. J. L. Platner, Section Head and Mr. P. D. Hess, Chief Engineer. Mr. R. Drushella is Project Manager. The management direction at Allis-Chalmers includes Mr. W. Mitchell, Jr., Director of Research and Mr. D. T. Scag, Assistant Director of Research.

This report was written by R. Drushella and R. Susnar, Project Engineer.

3.0 INTRODUCTION

This is the Phase II Report of The Engineering Research Study of a Hydrogen-Oxygen Fuel Cell Power Pack. The design and construction of the power pack are covered in the Phase I Report. The Fuel Cell State-of-the-Art as of November, 1961 was the basis for the design of the power pack.

The program consisted of designing, building, and evaluating the power pack with respect to operational characteristics, operational life, materials and energy balance problems as they are influenced by environmental and operational conditions. The purpose of the evaluation was to isolate and define engineering research problems.

The power pack was housed in a cabinet (Figure 1) and consisted of four 500 watt, 15 cell modules and supporting subsystems. Each module was designed to produce 12 volts at 42 amperes. One of the four modules was provided to supply power for the supporting auxiliaries. The other three modules were capable of producing a net power of 1.5 KW at 36 volts. (Refer to Phase I Report).

Previous to this contract, a large fuel cell system of this type had not been operated. Therefore, one of the major

3.0 Continued

program tasks was to develop an operational system for study. Since this was an engineering research program, no attempt was made to optimize the system.

The major areas of the present investigation were:

1. Environmental temperature load tests from +14°F to 125°F at loads varying from transient to steady state to determine problems associated with operating the fuel cells and system.

2. Material and energy balance studies of the system.

3. Open circuit voltage studies of the fuel cells.

4. Thermal characteristics study of the fuel cell modules.

The information for the material and energy balance studies, open circuit voltage studies and thermal characteristics studies was obtained from the environmental load tests.

4.0 SUMMARY

The Engineering Research Study of a Hydrogen-Oxygen Fuel Cell Power Pack was performed during Phase II of this contract.

The power pack consisted of four modules of 15 cells each and the necessary subsystem. Three modules were designed to supply 1.5 KW at 36 volts with the fourth module supplying parasitic power for the subsystem.

Environmental load tests were performed in controlled temperatures from 14°F to 125°F. The power pack performed, as designed, after modifications of the hydrogen recirculation system. The modifications consisted primarily of improved pressure controls and replacement of original valves.

The maximum continuous power delivered by the power pack was 750 watts at 49 volts. Attainment of designed output of 1500 watts was not possible because of insufficient pumping capacity of the recirculation system which, in turn, limited the maximum amount of reactant water that could be removed from the power pack.

Individual modules run singularly in the system were capable of producing rated capacity of 500 watts at 12.0 volts.

4.0 Continued

This rated output could be achieved with a major modification of the recirculation system.

Operation of the system at environmental temperatures from +14°F to 125°F was achieved without difficulty.

Materials and energy balance studies were made on the power pack. A current efficiency, within experimental error, of 100 percent was measured. Fuel cell and thermal efficiencies were measured and compared to theoretically calculated values and excellent agreement was found.

Open circuit voltage studies were made in an attempt to correlate OCV to life expectancy and cell performance. No definite correlation was found.

The thermal characteristics of the fuel cell modules were studied to evaluate the thermal design of the modules. The studies indicated good temperature management of the module at all levels of load from no load to overload.

The system performance for the purpose of this evaluation was adequate. For a practical fuel cell system, simplification of the moisture control method is desirable. Control techniques that will eliminate individual cell control are necessary.

5.0 FUEL CELL POWER PACK OPERATIONAL TESTS

5.1 System Checkout

This was the first large power pack of this particular type of fuel cell to be constructed and many experimental problems were anticipated that would require system modification before the system was completely operational; as a result, flexibility was required in the construction of such a unit. The cabinet-housed power pack provided easy accessibility to all subsystems, allowing repairs and modification to be made with a minimum of delay.

After the fuel cell modules had been constructed, each one was placed on a test stand and manually operated as a check-out procedure. All of the modules were checked out to assure that all cells functioned properly and that the module would meet design ratings. All of the modules performed satisfactorily and produced the following power. Each module was operated for about 15 minutes.

	Watts	Volts	Amps	O.C.V.
Mod. #1	528	12.0	44	16.2
Mod. #2	496	12.1	41	17.7
Mod. #3	526	11.7	45	17.1
Mod. #4	496	12.1	41	18.0
Mod. #4A	487	11.9	41	15.9

5.0 Continued

After the fuel cell check-out procedure, the modules were mounted on the cabinet.

The large number of valves, piping connections and instruments, presented many opportunities for fuel and oxidant leaks.

The system was checked out in two phases; the hydrogen subsystem and the oxygen subsystem.

The hydrogen subsystem check consisted of pressure testing the supply, exhaust, and recirculation sections. This was done by temporarily breaking and sealing the piping system and pressure checking to that point. This procedure was continued until the entire hydrogen subsystem was checked.

The oxygen subsystem check consisted of testing the supply and exhaust sections. The method employed was the same as that used in the hydrogen subsystem.

The electrical subsystem was tested to insure that all of the meters indicated correctly and that the hydrogen valves functioned properly upon a signal from the cell voltage controller.

Upon completion of the subsystem check-out, the system was put into operation. When the load tests were begun, it

5.0 Continued

became apparent that the hydrogen recirculation pump did not have sufficient capacity to allow moisture removal from all four modules operating at rated load. When operation above approximately 500 watts was attempted, the fuel cell performance would decrease due to accumulation of reactant water. Therefore, most of the initial environmental load tests were run with one, two or three of the four modules operating. As testing progressed, modifications were incorporated that permitted operation of all four modules but at a reduced capacity.

5.2 Environmental Load Test Series

The principle objective of the testing was to find the problems that developed in the fuel cells or the subsystem when the power pack, in its entirety, was subjected to operating temperatures from +14°F to 125°F. The tests performed under these varying environmental conditions were also used for the purpose of evaluating the following:

1. Material and Energy Balance
2. Open circuit voltage characteristics
3. Thermal Characteristics

A test chamber, which had a controllable environmental temperature range of -10°F to 125°F within ±3°F, was used for ...

5.0 Continued

tests conducted at other than room ambient conditions. The chamber was large enough to accommodate three operators and the entire fuel cell system and its components. (Figure 39)

The first tests were performed at room temperature followed by tests at elevated and then reduced temperatures. The reason for this arrangement was that it was believed the room and elevated temperature tests would have less overall affect on the system. It was anticipated that the lower temperature test series would prove destructive for the power pack.

The tests were arranged so that runs would be made at 125°F and then at 34°F. This gave a wide range for comparison of system operation.

There were a total of 48 runs performed on the power pack. Of these runs, 1 through 40, 47, and 48 were conducted in an ambient temperature of 75°F, runs 41 through 43 at an environmental temperature of 125°F, and runs 44 through 45 at an environmental temperature of 34°F and lower.

The runs between 1 and 23 were conducted for the purpose of fuel cell and system checkout and familiarizing the operators with the system. The data from these runs was used only for the purpose of studying open circuit voltage characteristics.

5.0 Continued

5.3 Room Temperature Tests

The room temperature tests were conducted at various load levels and with either 1, 2, 3, or 4 modules operating. The load on the fuel cell modules varied from 0 to 41 amperes under steady state load conditions.

As the testing progressed, it was necessary to make modifications in the system. These modifications are covered in the section on System Performance and Problems.

Summarized data of all the load tests is shown in Table 12. Most of the system "de-bugging" occurred during the room temperature tests. In reviewing the data it can be seen that initial system operation was achieved with one module operating and producing a maximum power of 413 watts at 12.3 volts (run 5). Starting with Test No. 17, two module operation was possible; and, during run 35, a maximum power of 678 watts at 22.6 volts was produced.

Three module operation was achieved during Test No. 36. However, performance above 678 watts was not possible because of system moisture removal limitations.

Four module operation was achieved during run No. 48. With a modification in the hydrogen recirculation system that

5.0 Continued

allowed an increased recirculation capacity, a maximum power pack output of 743 watts at 49.5 volts was achieved.

Figures 2, 3, 4 and 11 show power pack performance with one, two, three and four modules in operation.

5.4 Transient Response of the Power Pack to Changing Load Conditions

Two modules were used in this test series. The power pack was subjected to several loads under varying load conditions. The object of these tests was to study the relationship of time, current, and voltage.

Since these tests were of short duration, the system limitation of inadequate moisture removal did not prevent high loading of the power pack.

The fuel cell module was attached to an oscilloscope and load as is shown in Figure 33. The load was set at some predetermined value. Then the knife switch was either closed or opened depending on whether the load was being applied or taken from the module. The resulting relationship between time, voltage, and current was displayed on the oscilloscope where it was photographed by the camera. In this manner, the instantaneous change in load could be studied. These tests were run at currents ranging from 20 to 210 amperes which is 500% rated load.

5.0 Continued

The effect of slowly varying the load and changing from one load level to another during a run was studied during the course of running environmental load tests.

The results of this series of tests on varying loads are shown in Figures 12 through 22. Figures 12, 13, and 14 were recorded when various loads were removed from the fuel cell allowing it to return to open circuit voltage. Figures 15 through 18 have a time cycle of 1 second and show the transient response of the fuel cell when loaded. Figures 19 through 22 have a time cycle of only 200 milliseconds. These tests were near repeats of those in Figures 15 through 18 and show the equilibrium relationship of the current voltage and time in the milliseconds immediately after the load was applied.

These measurements indicated that when a load of rated capacity, (42 amperes), was instantaneously applied to the fuel cell, a spike current of 50 amperes (120% rated load) was produced. In a period of approximately 50 milliseconds the load had leveled off to rated capacity and the voltage had reached a steady state, (Figure 15C, 19C).

When a load of approximately 200% rated capacity was applied to the cell, the spike current available was approximately 110 amps

5.0 Continued

or 275% of rated capacity. The voltage of the system had obtained a steady state condition in approximately 50 milliseconds, (Figures 17A, 21B).

Recordings 17C and 19B were off scale and were voided.

When a load of 42 amps (rated capacity) was removed from the cell, the voltage recovered to a steady state condition in approximately 1 second (Figure 12C).

When a load of 100 amperes (2.5 times rated capacity) is removed from the cells, the voltage recovers to a steady state condition in 1 second also (Figure 14B).

5.5 Elevated Temperature Load Tests

The entire system was placed in the environmental test chamber and subjected to a temperature of 125°F. The modules 1, 2 and 4A were run at 10 and 16 amps in one continuous run. The tests were run at these low current levels because of limitations which existed in the subsystem and not the modules themselves. These limitations are discussed in detail under system problems.

The system was revised for the second high temperature run by excluding Module No. 2 and No. 3, and running only

5.0 Continued

Module No. 1 and No. 4A. The test was made at 20 amps for a period of four hours.

The third test required that the system be set up to run only one Module, No. 4A, which was tested above 30 amps for a period of 3.75 hours. (See Figures 5, 6, and 7 for power pack performance at the above conditions).

Operating the system at this high a temperature required certain changes in the operating procedure. The major change was in the temperature control system of the modules. The cooling fans were adjusted to their lowest speed and operated continuously throughout each run. This allowed the modules to operate between 125° and 140°F. The reason for this modification was that the temperature of the modules showed a tendency to increase rapidly and go beyond 160°F before the cooling fans would have a positive cooling effect.

Occasionally, automatic control of a cell would be lost, requiring manual control of the cell until it returned to normal. This situation occurred only five times in over 20 hours of operation at 125°F.

During this high temperature operation, no external heating of the modules was required.

5.0 Continued

The system as a whole reacted well during the elevated temperature testing. The only difficulty encountered was the occasional apparent drying of a cell within a module. This was not critical and was easily remedied by keeping the cooling fans running continuously. This permitted no cell temperature to get over 150°F.

The pump was performing satisfactorily with no leakage from the system. The voltage sensing and controller device required frequent adjustments as operating time at high temperature increased. The controllers are sensitive to temperature change; as the temperature increases, the reference voltage of the controller also increased. (Figure 24)

5.6 Reduced Temperature Load Tests

The sequence in the environmental testing was conducted with the power pack in a controlled operating temperature of 32° to 35°F.

The sequence of runs employed here was the same as that at the higher temperature.

The tests were performed using three modules at 10 and 15 amps; two modules at 20 amps and one module at 30 amps. (Refer to Figures 8, 9 and 10 for power pack performance).

5.0 Continued

One phase of the cold testing included a "cold soak" test of Modules 1, 2, and 4A. In this test the modules were allowed to cool down to 25°F. When they had reached this level, gas was admitted and a load was applied. The test was not completed due to leaks in the modules. (See System Problems Section).

The testing in an environmental temperature of 34°F and a module temperature of 150°F proceeded with few problems. The system performed as it was originally designed. The only problem encountered was in the water removal from the modules. The laboratory analysis of the water collected during this run showed an increased concentration of KOH. The quantity increased tenfold, going from a norm .75 g of KOH per liter to 7.9 g of KOH per liter.

A possible cause of the increased concentration of KOH in the exhaust water may have been the mechanical removal of water from the electrode face rather than evaporation. This could have a definite limiting effect upon the operational life of a fuel cell module at this condition.

The system could have been operated at considerably lower temperatures if the waste heat of the modules could have been recovered.

6.0 SYSTEM PERFORMANCE AND PROBLEMS

6.1 Performance

The operational load tests performed with the power pack demonstrated that the design of the power pack was satisfactory at a load level from 0 - 743 watts. Above 743 watts the hydrogen recirculation system did not have a sufficient capacity to remove the product water.

The modules themselves had the capacity to operate at any level from 0 to 500 watts each and, with modification to the hydrogen recirculation system, would have supported rated load of 1.5 KW.

The performance of the fuel cells and the system were studied individually and as an integrated power pack. The performance of both the fuel cells and system were satisfactory under all of the testing conditions.

The only problem arising from the fuel cell module was with the seal between the metal bi-polar plates. The seal consisted of wax impregnated into the asbestos electrolyte vehicle (refer to Phase I report). The coefficient of expansion of the wax is such that when the temperature of the module was reduced to 34°F the seal between the wax and bi-polar plate was broken and gas escaped from the module. Also, the wax had a high enough

6.0 Continued

vapor pressure that it had a tendency to vaporize and pass out of the module with the recirculated hydrogen gas. The wax then had a tendency to collect in the valves and restrict the flow of gas. Any excess wax remaining on the electrolyte vehicle before assembly had a tendency to melt and flow into the gas passages during construction of the module (Figure 37).

6.2 Fuel Cell Life

No particular run was designed to study the life of a fuel cell or module. The life studies regarded here are based on all of the modules run under all of the various conditions and loads.

The hours of operation for each of the modules is as follows:

1. Module 1 - 122.75 hours.
2. Module 2 - 73.5 hours.
3. Module 3 - 81.6 hours.
4. Module 4 - 60.9 hours.
5. Module 4A - 44.5 hours.

The only module to fail was No. 4. Its failure was not a failure in the true sense of the word. Its capacity degenerated

6.0 Continued

in power output from 500 watts to 180 watts. This module experienced severe testing conditions during system familiarization and checkout. The severity of operation resulted from the failure of the valves to control the flow of gas through the module. This over dried the cells and caused a degeneration of the modules' output. (See Figure 30)

Module 2 was exposed to a shelf life of seven months. This had no effect on the modules' operation when it was tested. (Figure 28)

Modules 1 and 3 were exposed to varying loads and test procedures throughout the entire test period without any adverse effects on output (see Figures 27 and 29).

Module 4A experienced most of its operation at elevated and reduced environmental conditions without any adverse effects. (Figure 31).

From the figures listed above, it can be seen that all of the modules experienced a limited degree of degeneration. This was expected, but to make an accurate prediction as to how long a particular module will last is difficult and can only be accomplished by performing an extended life test.

6.0 Continued

6.3 System Problems

There were several problems that arose during the testing phase. These were primarily with the portion of the system concerned with the removal of the product water. The pump did not have a sufficient capacity to circulate enough gas through the modules to remove the product water. The valves used to control the flow through the modules were bulky and by their very nature unreliable. Other components that caused difficulties were the gas pressure regulators and the voltage controller.

6.4 Recirculation System

The first few tests indicated that the hydrogen recirculation system was not giving a proper flow of gas through the modules or a satisfactory pressure differential across the module. The existing subsystem employed manually controlled valves on the inlet, outlet, and bypass of the hydrogen recirculation pump. These valves would not compensate for the full range of fluctuation of gas flow that occurred when the maximum and minimum number of hydrogen solenoid valves were open. An analysis and redesign of the recirculation subsystem provided a satisfactory arrangement that allowed a variable and controllable flow through, and a differential pressure

6.0 Continued

across the module. The new design eliminated the three manually controlled valves and employed an adjustable relief valve in the bypass around the pump. This allowed the adjustment of the differential pressure across the modules, which in turn helped to control the amount of gas passing through the bypass, if a minimum of the hydrogen solenoid valves were open. This eliminated the possibility of drawing a vacuum on any part of the hydrogen subsystem. The revised subsystem is shown in Figure 38

6.5 Recirculation Pump

The diaphragm pump partially performed the task required, but was very inefficient and had a low capacity. It was the only type of pump that could be located, without considerable development expense, which was of the approximate size and maintained a reasonable seal against hydrogen leakage. It was still necessary to modify this pump slightly by adding gaskets at the sealing surfaces and by incorporating a new gas inlet fixture.

After approximately 500 hours of operation, the diaphragm in the pump failed and had to be replaced. The failure appeared to be a result of normal wear.

6.0 Continued

The state-of-the-art of fuel cell operation, at the start of the contract, indicated that the amount of excess hydrogen required to remove the moisture was approximately five times the amount consumed. The operation of this system indicates that the amount required is larger under heavy loading conditions. The pump and piping installed in this system does not have the capacity to recirculate this required amount of hydrogen. This imposed a limitation on the load and the number of modules that could be operated. To operate a module at rated capacity, it was necessary to operate only one module at a time. Although this limitation prevented operating all of the modules as a unit at rated load, it did not prevent the evaluation of the system or fuel cells.

6.6 Pressure Regulators

After operating for a few hours, the differential pressure regulator would not allow a sufficient amount of gas to enter the system. Also, it would not maintain a constant pressure on the exhaust side. The differential pressure regulator was removed and returned to the manufacturer for repairs. Upon its return, the repaired regulator was installed in the system, but failed again after approximately 28 hours operation.

6.0 Continued

At this time the differential pressure regulator was replaced with two standard type gas regulators; one in the hydrogen line and the other in the oxygen line. The regulator installed in the oxygen line was a Fisher-Governor Type 67-R and the one in the hydrogen line was a Fisher-Governor Type 95-L.

With these regulators it was possible to obtain the necessary flow rate and maintain a constant inlet pressure of 9 pounds, $\pm$ 0.5 pounds. The subsequent operation of the system has shown that control to within these limits was satisfactory.

6.7 Valve Modification

During the load tests the solenoid valves in the hydrogen exhaust lines continually failed. These valves failed due to gas leakage at the inlet collars.

A thorough metallurgical and microphotographic analysis indicated the cause of failure. There were four distinct marks on the threads of each collar which appeared to be caused by a dull four fluted tap. All of the failures occurred along one of these lines and appeared to be stress failures. A spot check of the collars on the remaining valves revealed several additional failures.

This difficulty was eliminated by replacing the damaged collars and all of the stainless steel fittings in the collars

6.0 Continued

with plastic fittings. This allowed a sealing between the collar and tube fittings without imposing a high stress on the collar.

The original solenoid valves continued to be a source of trouble during the operational tests. Some of the solenoids would receive a signal from the voltage sensor and, in turn, close. In the closed state, the hydrogen continued to leak through the valve, causing the cells to become dry. Other valves, however, did not close after receiving a signal from the voltage sensor.

The cause of the leakage through the valve was a poor fit between the gasket and ball. When the valve became warm from the hot hydrogen gas passing through it, the seal between the gasket and ball would be lost, resulting in a gas leakage. The cause of some of the valves not closing was that the plunger would travel too far and cause a deformation of the valve body. As this deformation enlarged, it would cause the plunger to bind and not move freely.

The three way toggle valves, which permitted the monitoring of individual cell flow, worked on the same principle as the solenoid valves in that they employed a ball and gasket.

6.0 Continued

They functioned longer than the solenoid valves but soon failed in the same manner. In their case, leakage was from the system.

In an attempt to solve the problem of repeated valve failure, four steps were taken:

1. In an attempt to use the original solenoid valves, two steps were taken. Some of the inlet adapters were machined to increase the pressure on the internal gasket. Also, some of the valves were nickel plated to determine if any failures were due to corrosion.

2. A commercially available air actuated solenoid valve (Series 250 AE-2, manufactured by Humphrey Products Div., General Gas Light Company) was installed on the system to evaluate its capabilities. This valve does not employ a seal between a gasket and ball. The gas passage is completely enclosed between diaphragms.

3. A commercial ball bearing cam actuated valve was modified to be actuated by a solenoid. This valve also completely enclosed the gas passage between diaphragms.

6.0 Continued

4. A complete manifold block, which contained the solenoid valves and manifold passages in one piece, was investigated.

The attempts to modify the existing solenoid and three-way valves to make them suitable for this service were not satisfactory. The use of metals with different coefficients of expansion made it impossible to maintain a seal and ease of motion over the temperature range which these valves encountered. The valves that were nickel plated did not operate satisfactorily because of the change in clearance due to the addition of the nickel plate.

The tests with the air actuated solenoid valve indicated that the valve operated satisfactorily.

The ball bearing cam valve which was modified to be activated by solenoid, also functioned very well.

The possibility of incorporating the solenoid valves and manifold all in one block as a complete unit for each module was the most desirable solution. The advantages of this system were compactness and the elimination of joints which were potential leakage areas. However, cost and delivery time prevented use of this method.

6.0 Continued

When all of the factors obtained from the four steps had been considered, it was decided to replace the valves in the existing system.

The original solenoid valves were replaced with the air actuated solenoid valves which were proven to be reliable. The three-way valves were replaced with a small three-way valve that worked on the same principle as the solenoid valve with the diaphragms;and the flow adjustment valve was replaced with a stainless steel needle valve that afforded a finer control over the entire range of flows.

These valves were arranged in a compact manner and mounted on a panel board. There was one panel for each module. The valves on each panel were then connected by a series of manifolds fabricated from stainless steel tubing. This arrangement made a neat and compact valving system. These panels are shown in Figure 23.

After the new valving system had been in operation for several hours (approximately 100), the three way valves began to cause trouble. Upon investigation, it was revealed that the valves were becoming clogged with a foreign compound. Further investigation revealed that the compound was a portion of the

6.0 Continued

wax which was used on the asbestos electrolyte vehicle as a sealant. The port in the three-way valve was 6/32 inch in diameter and had a clearance of 0.040 inch between the seat and stem. This opening was so small that the minute quantities of wax which came out of the cell accumulated in this area and eventually clogged it. As it was not practical to remove the cause of the foreign material, and, as most of the data requiring the measurement of individual flow was completed, the three-way valves were removed. A straight by-pass was used in place of the three-way valve. The remaining solenoid and needle valves were mounted in the same panel (Figure 1).

The failure of the original solenoid and three-way valves to form a tight seal in the closed position, resulted in some of the cells in module number four becoming too dry, contributing to the failure of this module.

6.8 Voltage Controller

The voltage controller which operates the solenoid valves as a function of the cell voltage is described in the Phase I report. During the environmental test, it was observed that the temperature had an effect on the operation of the controller. The set point to which the cell voltage was compared would fluctuate as the temperature changed. The curve in Figure 24

6.0 Continued

illustrates the undesirable relationship between temperature and voltage set point. It is possible to modify this controller in such a manner that it would not be affected by temperature. This modification is quite extensive and expensive. The controllers used on this system had a manual control on the set point which was adjusted when the temperature was changed.

There are basic factors that indicate this method of control would not be compatible with the hydrogen-oxygen gaseous fuel cell under the extremes of operating conditions required. These factors are:

1. The voltage controller operates on the principle of comparing the voltage of the fuel cell to a preset value.

2. The basic principle upon which this control system operates is that there is a distinct relationship between the voltage and the moisture content of the cell. This relationship is shown by a typical curve as illustrated in Figure 25.

The preset values to which the voltage of the cells were compared were regulated by hand. The difference between the open and close voltage was 0.04 of a volt. The curve illustrated

6.0 Continued

in Figure 25 is for one current load on a cell. As the current drawn from a cell is changed, the curve will shift. As a result, a family of curves is generated when a cell is subjected to a varying load cycle, Figure 26.

When a power plant is required to operate over the extremes of loads (0 to 100% overload) as was required in this application, it is necessary that the values in the controller be at such a level that regardless of the load, the cell would not be allowed to cross over to the dry side. Previous operation of hydrogen and oxygen fuel cells had shown it to be most desirable to operate on the wet side of the peak. This, in turn, required that the controller set values change with the load or that they be set at such a value that regardless of load, the cell would not become dry.

At this time, there was no method of changing the set values of the controller as a function of the load on the cell. As a result, if the load was going to fluctuate, the controller must be manually set at a value so that regardless of the load, the cell would not become dry.

7.0 MATERIALS AND ENERGY BALANCE STUDIES

During these studies, an accounting of the materials entering and leaving the system was made. Also, an accounting of the total energy input to the fuel cells and system was made and equated to the electrical energy and heat energy produced by the fuel cells and system. The current, cell, and thermal efficiencies of the fuel cells were calculated from measured test parameters and compared to their theoretically calculated values.

The performing of a materials and energy balance for a system of this size at first presented a perplexing problem. In attempting to calculate materials balance and current efficiencies from data taken, it was found that data collected in a single run did not yield accurate results. This was due to the complexity of the subsystem assemblies where the reactant water could accumulate and not be removed. This problem was overcome by utilizing the data taken in an entire series of consecutive tests and then affecting a materials balance. Thus, the error due to accumulated and trapped reactants in the system was small.

Materials balance and efficiency calculations are based on standard data collected in the process of a normal run. It

7.0 Continued

was determined in the process of testing and calculating results that the original instruments for collecting data had varying degrees of accuracy. This led to the use of an ampere-hour meter for the accurate measurement of current produced and a Gas Wet Test Meter, a totaling device, for the measurement of hydrogen into the system. These two instruments greatly increased the accuracy of measurement over the previously used rate meters.

The reactants into, the electrical energy out of, and the water removed from the system were measured as follows:

1. Hydrogen gas was measured using a wet test meter. This is an integrating meter with a measurement accuracy to within 1/2 percent.

2. Oxygen gas was measured using a rate type meter.

3. Voltage measurements were recorded at set time intervals.

4. An ampere-hour meter integrated the total ampere-hours produced.

5. Product water measurements were made by:

   a. Measuring the volume of water condensed in the heat exchanger located in the hydrogen exhaust line.

7.0 Continued

b. Taring the gas drier tank located in the hydrogen line.

c. Taring the gas drier tank located in the oxygen exhaust line.

The environmental temperature of the system ranged from 14°F to 125°F. However, the temperature of the fuel cell modules was maintained constant at about 140°F by the temperature control system.

Individual runs were conducted for varying durations of time. The longest of all these runs were Numbers 32 and 33, which were conducted as a continuous single run lasting a total of 34.25 hours. The average run considered in this test series lasted approximately seven hours.

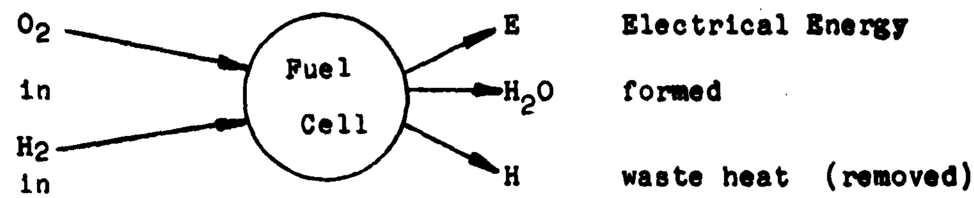
Materials and energy balances were not computed for runs below Number 32 because of the known inaccuracy of data taken. Tabular data for the materials and current efficiency calculations are in Table 1.

The overall reaction of the fuel cell is:

$$H_2 + 1/2\ O_2 = H_2O + \text{electrical energy and heat}$$

7.0 Continued

Diagrammatically this can be shown as below:



7.1 Materials Balance

In calculating the materials balance, the following formula was used:

$$9 \quad \text{Hydrogen consumed by weight (measured)} = \text{weight of water produced}$$

The reason for using this method is that the hydrogen input to the system was very accurately measured; whereas, the oxygen was not, but stoichiometrically eight parts by weight of oxygen must combine with 1 part by weight of hydrogen. Refer to Figure 32 for material balance calculation. The calculation shows that all of the materials are accounted for within 1.0 percent.

7.2 Efficiency Studies

Current Efficiency

Current Efficiency (N_c) may be defined by the following equation:

7.0 Continued

$$N_c = \frac{\text{total ampere-hour output measured in the external circuit}}{\text{theoretical ampere-hour content of the hydrogen fuel consumed}} \times 100\%$$

This efficiency evaluates the ability of the fuel cell to deliver the theoretical current equivalent of the fuel consumed to the external circuit. Figure 32 shows the current efficiency calculation using values from Table 1. The current efficiency is shown to be 98.5%.

Cell Efficiency

The cell efficiency, N_v, may be defined by the following equations:

$$\text{Cell efficiency (measured)} = N_v = \frac{\text{Electrical energy delivered to external circuit (measured)} \times 100\%}{F}$$

where F = Maximum free energy of the fuel into the system.

$$\text{Cell efficiency} = N_v \text{ calculated} = \frac{\text{Actual working voltage}}{\text{Theoretical voltage}} \times 10\ldots$$

The above efficiency indicates the ability of the fuel cell to convert the theoretical maximum free energy available.

The calculation for run 48, shown in Figure 32, compare N_v measured to the calculated value of N_v. The measured N_v is 64.3% and agrees within 2.2 percent of the calculated value.

7.0 Continued

Thermal Efficiency of the Fuel Cell

The thermal efficiency, N_T, may be defined by the following equation.

$$\text{Thermal efficiency} = N_T = \frac{\text{measured electrical output in external circuit}}{H} \times 100$$

where H is the total thermochemical energy input to the fuel cell.

Figure 32 shows the measured thermal efficiency of the fuel cells during run 48 to be 53.5%. When the measured thermal efficiency is compared to the calculated thermal efficiency, the difference is 1.9 percent.

The calculated thermal efficiency is defined as:

$$N_T \text{ calculated} = \frac{\text{actual working voltage}}{\text{theoretical voltage}} \times \frac{F}{H} \times 100\%$$

System Efficiency

System efficiency, N_s, may be defined by the equation:

$$N_s = \frac{E\ \text{net}}{H} \times 100\%$$

where $E\ \text{net} = E\ \text{gross} - E\ \text{auxiliaries}$

The most efficient system will be one requiring the least amount of auxiliary power.

7.0 Continued

Figure 32 shows the system efficiency of run 48 to be 33.1%.

Since this is an experimental system, no attempt was made to use a specially designed hydrogen pump or pump motor. Thus, the system efficiency is lower than would be expected for a refined design.

Overall system efficiencies of 48 percent are reasonable to expect with the system concept.

8.0 OPEN CIRCUIT VOLTAGE STUDIES

The objectives of the open circuit voltage tests were to observe, record, and evaluate the data in an effort to learn more about the behavior of the open circuit voltage. This information was obtained from cells combined into modules and functioning under the various operating conditions.

The information of interest was the open circuit voltage at various stages of operation and under various conditions, such as:

1. Before and after admitting gas to the modules after a prolonged period of inoperation.
2. Immediately before and after and during a test run.
3. Upon removal of a load.
4. The affect of temperature.
5. The affect of time and usage.

The OCV history was categorized into three groups, corresponding to the environmental tests performed at:

1. Ambient temperature.
2. Reduced temperature.
3. Elevated temperature.

8.0 Continued

The voltage of each cell within a module was monitored by attaching an electrical lead from a 15 station selector switch to the metal cooling fins of each cell within the module. Attached to the switch was a 0 to 1.5 volt meter. The motor driven selector switch rotated continually and, in turn, monitored the voltage of each cell within the module. One of these switch and voltmeter devices served each module.

The OCV of each cell was recorded at the beginning of every test. On some of the tests, the open circuit voltages were recorded before the gas was admitted to the cells; midway through the test, and at the end of the test. The open circuit voltage was monitored midway through a test by removing the load and immediately reading the values of voltage and then replacing the load. The readings at the end of a test were recorded immediately after removing the load from the module.

With this procedure, the open circuit voltage was monitored under all the environmental conditions as well as all the operating conditions to which the modules were subjected.

The time necessary for a module to return to OCV after being subjected to loads of various values from partial to overload condition was determined by attaching an oscilloscope in a module electrical circuit as illustrated in Figure 33.

8.0 Continued

To determine the effect of pressure, gas was admitted to the module at 1 pound per square inch gage pressure and the voltage of the module recorded. The pressure was increased by 1 psig increments to 10 psig. The voltage at each increment was recorded. The test was conducted at a temperature of 80 degrees fahrenhiet. The results of the test are shown in Figure 34.

After a prolonged period of inoperation and isolation from a gas supply, the open circuit voltage of any given cell would decrease to some value between zero and maximum.

However, voltage of the cell would immediately increase to its maximum value upon admitting gas, at operating pressure, to the cell. The rate of increase varied with each cell. Some of the cells would reach their maximum instantaneously, and others would take several minutes.

It was observed upon several occasions that when a cell was in a relatively dry condition when shut down, its open circuit voltage would be reached rapidly and attain a somewhat higher value than normally, when gas was admitted to the cell again. If wet when shut down, the OCV would be attained slowly and attain a slightly lower than normal value when started up.

8.0 Continued

The open circuit voltage of the modules before and after tests is shown in the tables of condensed data; Tables 3, 4, 5, 6 and 7. Runs number 22, 30, and 32, show open circuit voltages taken during a run. Runs number 1, 19 thru 22, 25, 27 thru 32, 35, 38, and 39 show open circuit voltages taken at the end of a run. All of the tests show the open circuit voltage at the start of the run.

The open circuit voltages taken during a run indicates that it recovers very fast and to very near the voltage prior to the start of the run; (Table 8).

The information, as plotted in Figure 34, indicates that the open circuit voltage is affected by pressure. As the pressure was increased, the OCV increased, and as the pressure was decreased, the OCV decreased. The degree of change varied with each module, but the direction of change was the same.

The comparison of open circuit voltages taken on the initial runs to those taken on the last runs indicates that time and use cause very little depreciation of the open circuit voltages (Table 9).

Module No. 2 was operated on its initial check out, run B, and then allowed to stand idle until run No. 32. This was a period of six months. During this prolonged period of standby,

8.0 Continued

the module was subjected to all of the environmental conditions imposed on the operating modules. As is shown in the data, time alone has very little affect on the open circuit voltage. Module No. 1 was subjected to heavy use during the Phase II testing. The results of the data, as shown in Table 3, indicate use, under a range of environmental conditions, also has little affect on the open circuit voltage.

The effects of temperature on the open circuit voltages are illustrated by the data from run 29 in Tables 3 and 5. The increase of temperature from 75° to 135° changed the open circuit voltage from 15.6 to 15.8 in module one and from 15.9 to 16.1 in module three. This is only a change of 0.20 volts for 15 cells.

The analysis of data and observations of the modules under test conditions has led to the following conclusions.

The open circuit voltage will always decrease when the supply of gas is cut off from the cell. It is felt that this is caused by a slight amount of internal electrical leakage between the electrodes. The rate of decrease of the voltage apparently is a function of the moisture content of the cell, when shut down. The moisture content of the cell, when shut down, affects the rate of recovery and has a definite effect on the value of the new open circuit voltage. If a cell is wet, the open circuit voltage will not attain a value as high as

8.0 Continued

normal; and conversely, if it is dry, it will attain a voltage higher than the normal open circuit voltage. As soon as the cell is operated and brought back to normal moisture content, the open circuit voltage will return to its normal value.

There has been no indication that the mois 're content of the cell, when shut down, has any relation to the level to which the open circuit voltage decreases.

The environmental conditions or the loads imposed upon a cell do not have any apparent effect on the rate of decrease or the final value of open circuit voltage reached.

Upon allowing gas to enter the cells, the open circuit voltage will recover to near its previous value. The rate of recovery does not depend upon the previous environmental or load conditions.

The removal of a load from the cell will allow the voltage to recover immediately to the normal open circuit value. The open circuit voltage of a cell with the gas supply attached is not affected by previous loading or environmental conditions.

An inoperative storage period of 6 months, with a temperature range of 125°F to 140°F did not have any effect on the open

8.0 Continued

circuit voltage of the cell. The extensive operation of a fuel cell under varying load conditions for a period of at least 8 months did not cause any noticeable change in the open circuit voltage. Also, operation under environmental conditions of 125°F to 14°F had little or no affect on the open circuit voltage.

The open circuit voltage of a cell increased with pressure and temperature.

Little is known in regard to the possible correlation of OCV and the life expectancy and performance of an individual cell and module. Although the data obtained was extensive, it was not conclusive enough to make these correlations.

9.0 THERMAL CHARACTERISTICS OF THE MODULES

The objective of observing and recording the temperature distribution within a module operating under various environmental conditions was to evaluate the present design for control of temperature and removal of waste heat from the cells.

One of the functions of the metal bi-polar plates is to transfer the heat from the inside of the cell to the cooling fins outside of the cell where it is then transferred to the surrounding air. (Refer to page 7, Phase I report). Air is forced over the surface of the cooling fins by a fan that is located relative to the module as shown in Figure 35.

Temperature distribution data was taken to determine the temperature distribution over the surface of the electrode. This was done by locating five iron-constantan thermo-couples at different locations as shown in Figure 36. The temperature of the cell was raised to 150°F and operated. The temperature of each thermocouple was monitored and recorded. Other data was taken to determine the temperature gradient across a module. This was done by placing an iron-constantan thermocouple in each cell. The temperature of each cell was monitored under all ambient and environmental operating conditions.

The results of the test to determine the temperature gradient across the surface of the cell are shown in Table 10. The location of the thermocouples referred to in this table are shown in Figure 36.

9.0 Continued

This data shows that a temperature gradient across the surface of a cell is very small and insignificant when the cell is operated at its rated load. As a result of this information only one thermocouple, located in the end of each cell, was used to determine the temperature gradient across the module.

The results of the data taken in two typical runs spaced throughout the testing phase, 26 and 48, are shown in Table II. These results show that the temperature across a module is uniform. The deviation of any one cell from the norm is not more than 3 degrees. Some tests were performed where the modules were not heated with the heating pads prior to the test. It was possible to operate the cell starting at room temperature and allowing them to rise to operating temperature from their own waste heat. Starting operations at room temperature necessitated using a large flow of gas to remove the by-product water. This coupled with the fact that as the module rose in temperature, the amount of gas necessary to remove the same amount of water would vary, requiring that the flow rate of hydrogen through the module be continually adjusted. These adjustments required close supervision of the system by the operator until the module was up to operating temperature, 150°F, before it could be put on automatic control.

9.0 Continued

The operation of the system in an environmental temperature below 30°F required that the modules be insulated. This was necessary because the module would lose heat at such a rate that it would fall below the required operating temperature.

The tests have proven the design of the fuel cell module in respect to heat removal and temperature control.

The most desirable method of starting the modules is to heat them to operating temperature before the beginning of operation.

The operation of the modules in an environment of reduced temperature necessitates that some method be employed to conserve enough of the waste heat to maintain the module at operating temperature.

10. CONCLUSIONS

The tests conducted under Phase II of the DOFL contract show that the fuel cell power pack operated satisfactorily under various conditions.

The degree of successful testing was directly related to the reliability of the supporting subsystems and their components. The major cause of inoperation or test shutdown was the failure of one or the other subsystems or of their components. Testing was rarely impeded by the fuel cells themselves.

The fuel cells dissipated all of their waste heat to the surrounding atmosphere under all of the test conditions. In the course of dissipating this waste heat, they were also able to maintain an even surface temperature as well as an even temperature throughout the module.

The testing at ambient, reduced, and elevated temperature showed that a variable environmental temperature of $14^{o}F$ to $125^{o}F$ has no apparent effect on the fuel cells or the reactions occurring in them. However, the subsystem and its components are definitely affected.

The materials balance and efficiency studies have shown that the current efficiency is 98.5 percent, or essentially

100 percent within experimental error. The measured fuel cell efficiency and the thermal efficiency agree to within 2.0 percent of their theoretical values.

If a system of this type is to operate at temperatures lower than about 20°F, further steps will have to be taken to conserve the waste heat from the fuel cells. It will be necessary to use this waste heat to warm the system so that the by-product water removed from the fuel cells will not freeze before it is collected and ejected from the system.

The basic principle of the system and its components with the exception of the hydrogen recirculation pump and the moisture control mechanism will operate satisfactorily under any of the conditions tested. The basic problem areas with the system were the hydrogen recirculation pump and the moisture control mechanisms and its related valving.

The hydrogen recirculation pump used was a diaphragm type. This pump did not have a sufficient capacity and was inefficient.

The control mechanism, as employed in this application, has four inherent characteristics that make it less than satisfactor for this type of application. The basic principle upon which this mechanism operates is that for any given load, the relationship between the moisture content of the cell and its voltage be repeatable. It requires that the voltage limits, between which the solenoids operate, be manually adjusted for every large change in load applied to the fuel cell. Also, it requires that the valves regulating the rate of hydrogen passing through the cell be manually adjusted with a large change in load on the cells. One of the most cumbersome is the requirement for a large number of valves.

Time, service, and storage at environmental temperature of 14^{o} to $125^{o}F$ have little or no affect on the open circuit voltage of the cells. The fuel cells can be operated in this same range of environmental temperature providing they are maintained at a temperature which will permit the excess hydrogen to remove the by-product water.

The complexity of this system indicates that a more compact system with a less complex mode of operation be developed. Maximum system performance was not possible because of the unreliability of the numerous components. Rather than spend the effort and time required to develop reliable components, it seems far more logical to develop a fuel cell system which doesn't require a massive or complex subsystem.

Such a system would not require a recirculation system or a voltage regulated purge control for moisture removal. It would, in fact, be a static system.

An alternative of this would be a system which would have a continuous recirculation of gas through the fuel cell. The moisture content of the cells would be maintained by preconditioning the gas going into the fuel cell. The preconditioning would actually be a partial saturation of the gas with water. This would then restrict the amount of water the gas would be able to remove from the electrode face. An appropriate name for this type of system would be Vapor Pressure Control. This system would not require the numerous regulating valves but would have a continuous recycling of the hydrogen gas.

Initial research studies of these systems were commenced about a year ago with laboratory modules being built and tested. These systems are known as the Allis-Chalmers Static Fuel Cell System and the Allis-Chalmers Vapor Pressure Control Fuel Cell System.

In the event of any future hydrogen-oxygen fuel cell contracts, it is recommended that the work be done on either of these two new systems. This is because of their inherent simplicity in comparison to the mechanical complexity of the system which was used under this contract.

TABLE 1

Tabulated Values for Materials Balance and Current Efficiency Calculations

No. of Mods.	Run No.	Ampere Hours	Hydrogen consumed in grams	H_2O cc collected	Theoretical H_2O formation based on gas
		Room Ambient Temperature Runs			
	32				
2	33	12,885	505.9	4,703	4,553.1
2	34	3,091	120.6	937	1,085.3
2	35	5,160	212.8	1,000	1,915.0
3	36	3,155	109.0	737	981.0
1	37	2,070	72.1	1,027	648.8
1	38	1,890	79.3	675	713.7
1	39	1,830	56.8	430	511.2
1	40	1,980	71.5	760	643.5
		Runs at 125° F			
3	41	2,700	110.3	1,157	992.7
2	42	2,400	99.1	845	892.0
1	43	1,620	64.2	576	577.8
		Runs at 34° F and lower			
3	44	3,471	95.6	940	860.4
2	45	3,960	151.4	1,277	1,363.0
1	46	2,190	96.6	734	869.0
Sum Total		48,402	1,845.2	15,798	16,606.5
				750 *	
				16,548	

* A comparison of the theoretical water formation based on gas consumption and that volume which was actually collected shows a shortage of 795 cc of water. After the last test had been completed the system was allowed to stand, with all valves and pipes open. This permitted all of the excess water to accumulate. The final additional amount collected was 750 cc.

TABLE 2

TABULATED EFFICIENCIES

Run Number	Current Efficiency	Fuel Cell	Theoretical Fuel Cell	Thermal	Theoretical Thermal
32	103.0%	71.0%	69.2%	59.25%	57.6%
37	106.5	67.3	63.4	55.9	52.8
42	103.0	66.5	65.0	55.3	54.0
48	97.2	64.3	66.5	53.5	55.4

TABLE 5

OPEN CIRCUIT VOLTAGE HISTORY OF MODULE NUMBER 1

Run No.	Date	Max. Amps	Length of Run Hrs.	Module Temp.F	Operating Volt	Individual Cell Open Circuit Voltage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OCV	Comments
A	4 May 62	44	.5	150	11.8	1.06	1.06	1.06	1.04	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.04	1.06	1.06	1.06	15.86	Initial - check out run after construction
16	21 Sept 62	25	6.0	130	12.1	1.05	1.03	1.03	1.03	1.03	1.04	1.04	1.05	1.03	1.04	1.06	1.04	1.05	1.04	1.05	15.8	Initial
17	28 Sept 62	20	5.75	140	13.0	1.05	1.04	1.04	1.04	1.07	1.06	1.05	1.07	1.04	1.07	1.05	1.04	1.04	1.06	1.05	15.8	Initial - run in conjuction with mod #3
18	1 Oct. 62	15	1.75	150	13.5	1.20	1.20	1.20	1.20	1.20	1.10	1.40	1.20	1.40	1.20	1.40	1.30	1.20	1.20	1.20	18.6	Initial
19	2 Oct. 62	15	3.5	145	12.9	1.02	1.01	1.01	1.01	1.02	1.02	1.06	1.06	1.06	1.05	1.04	1.04	1.02	1.04	1.03	15.5	Initial
20	3 Oct. 62			140		1.06	1.04	1.06	1.04	1.08	1.05	1.08	1.06	1.08	1.06	1.06	1.04	1.02	1.04	1.02	15.8	Initial
		15	8	140	13.0	1.04	1.01	1.01	1.01	1.03	1.01	1.02	1.02	1.03	1.02	1.02	1.02	1.02	1.04	1.02	15.3	Final
21	4 Oct. 62																					No OCV recor'ed
22	8 Oct. 62			85		1.09	1.07	1.08	1.09	1.09	1.10	1.08	1.08	1.09	1.08	1.08	1.08	1.09	1.08	1.09	16.3	Initial - aft r four day shut down
				150		1.04	1.03	1.04	1.04	1.04	1.04	1.04	1.04	1.06	1.07	1.04	1.04	1.03	1.06	1.07	15.7	Mid-run
		10	7.75	150	13.5	1.05	1.04	1.04	1.04	1.05	1.04	1.04	1.04	1.06	1.04	1.04	1.04	1.02	1.05	1.05	15.6	Final
23	9 Oct. 62	20	6	150	12.5	1.08	1.04	1.05	1.04	1.05	1.06	1.07	1.08	1.08	1.08	1.05	1.06	1.08	1.06	1.06	15.9	Initial
24	10 Oct. 62	15	1.5	145	13.0	1.08	1.06	1.07	1.07	1.05	1.06	1.05	1.06	1.06	1.07	1.07	1.06	1.04	1.08	1.04	15.9	Initial
25	11 Oct. 62	15	0.75	135	13.0	1.05	1.03	1.04	1.05	1.05	1.05	1.04	1.06	1.09	1.09	1.07	1.07	1.05	1.06	1.06	15.8	Initial
26	11 Oct. 62	15	4.3	140	12.8	1.05	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.04	1.03	1.03	1.04	1.04	1.04	15.6	Initial
27	12 Oct. 62			105		1.03	1.01	1.03	1.03	1.04	1.03	1.03	1.02	1.04	1.03	1.03	1.03	1.02	1.02	1.02	15.4	Initial
		20	7.25	150	12.3	1.03	1.03	1.03	1.03	1.04	1.03	1.05	1.05	1.06	1.04	1.04	1.04	1.04	1.05	1.03	15.6	Final
28	12 Oct. 62			135		1.05	1.06	1.06	1.07	1.08	1.05	1.07	1.07	1.08	1.06	1.05	1.05	1.05	1.06	1.06	15.9	Initial
		20	2.3	150	12.5	1.04	1.06	1.06	1.07	1.08	1.04	1.06	1.09	1.09	1.06	1.05	1.06	1.06	1.04	1.06	15.9	Final
29	15 Oct. 62			75		0.73	0.50	0.42	0.54	0.59	0.59	0.64	0.62	0.50	0.40	0.59	0.46	0.43	0.37	0.52	7.9	Initial - after three days with gas supply shut off
				75		1.05	1.04	1.02	1.04	1.04	1.03	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	15.6	Initial - instantaneous recovery when gas turned on
				135		1.06	1.05	1.04	1.05	1.06	1.05	1.07	1.06	1.06	1.05	1.05	1.06	1.04	1.07	1.05	15.8	Initial - module now heated to operating temp.
		20	4.25	150	12.5	1.06	1.05	1.05	1.06	1.06	1.05	1.05	1.05	1.07	1.05	1.05	1.06	1.05	1.06	1.06	15.8	Final
30	17 Oct. 62			140		1.06	1.05	1.07	1.07	1.08	1.07	1.08	1.08	1.08	1.08	1.07	1.07	1.05	1.07	1.06	16.0	Initial
				150		1.04	1.04	1.03	1.06	1.06	1.03	1.03	1.03	1.06	1.03	1.02	1.01	1.01	1.04	0.97	15.5	Mid-run
		25	6	160	12.2	1.04	1.03	1.03	1.01	1.01	1.02	1.01	1.04	1.05	1.03	1.03	1.03	1.03	1.03	1.05	15.4	Final
31	19 Oct. 62			75		0.91	0.80	0.0	0.0	0.68	0.69	0.61	0.62	0.50	0.44	0.46	0.15	0.06	0.07	0.59	6.6	Initial - retained OCV - system has been off for two days
				125		1.05	1.04	1.04	1.02	1.02	1.03	1.03	1.03	1.03	1.01	1.02	1.02	1.00	1.00	1.02	15.4	Initial - instantaneous recovery
		25	3.5	130	11.5	1.05	1.06	1.06	1.04	1.05	1.05	1.05	1.05	1.07	1.06	1.06	1.05	1.05	1.02	1.05	15.8	Final -
32	19 Nov. 62	10	21.5	140	12.8	1.04	1.05	1.06	1.06	1.06	1.04	1.06	1.06	1.05	1.06	1.06	1.04	1.06	1.04	1.04	15.5	Initial
				125		1.06	1.06	1.07	1.07	1.08	1.08	1.08	1.08	1.07	1.08	1.07	1.07	1.07	1.06	1.07	15.7	3 Hrs. later before any load applied
				135		.99	1.03	1.02	1.00	1.04	.98	.99	1.03	1.04	1.04	1.02	1.02	1.01	1.01	1.02	15.2	Middle of run
						1.02	1.01	1.00	1.02	1.01	1.02	1.02	1.01	1.02	1.01	1.00	1.00	1.00	1.00	1.01	15.3	Final
33	20 Nov 62	18	7.5	100	11.7	1.04	1.03	1.02	1.03	1.03	1.03	1.04	1.03	1.02	1.01	1.00	1.00	1.00	.99	1.01	15.2	Initial
34	28 Nov 62	20	5	138	11.5	1.03	1.03	1.03	1.04	1.04	1.03	1.03	1.03	1.06	1.06	1.04	1.05	1.04	1.04	1.04	15.6	Initial
						1.04	1.04	1.04	1.04	1.04	1.03	1.04	1.04	1.05	1.04	1.04	1.04	1.03	1.00	1.00	15.0	Final
35	30 Nov 62	21	4	145	11.2	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	.99	1.04	1.04	1.04	1.05	1.04	1.04	15.7	Initial
						1.04	1.04	1.04	.96	1.04	1.03	1.03	.99	1.30	1.03	1.03	1.02	1.02	1.01	.99	15.6	Final
36	26 Dec 62	15	5	135	12.3	1.02	1.02	1.02	.98	1.02	1.01	1.02	.94	1.01	1.02	1.01	1.01	1.01	1.01	1.02	14.8	Initial
41	9 Jan 63	15	5	135	12.3	1.05	1.05	1.05	1.03	1.06	1.06	1.06	1.06	1.04	1.03	1.06	1.06	1.05	1.04	1.05	15.6	Initial
44	11 Jan 63	15	5	110	12.0	1.05	1.04	1.03	1.02	1.03	1.04	1.05	1.05	1.06	1.05	1.05	1.05	1.05	1.03	1.04	15.5	Initial
47	30 Jan 63	0	0	80	-	1.04	1.04	1.02	1.02	1.01	1.01	1.03	1.03	1.04	1.04	1.02	1.01	0.98	1.01	1.03	15.5	Taken at operating pressure standard

TABLE 4

OPEN CIRCUIT VOLTAGE HISTORY OF MODULE NUMBER 2

Run No.	Date	Max. Amps	Length of Run Hrs.	Module Temp. F.	Operating Volt	Individual Cell Open Circuit Voltage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OCV	Comments
32	19 Nov 62	10	21.5	140	12.8	1.06	1.06	1.05	1.05	1.05	1.04	1.05	1.06	1.04	1.06	1.04	1.05	1.07	1.05	1.05	15.8	Initial
						1.08	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.06	1.07	1.07	1.07	1.08	1.07	1.06	16.1	3 hours later.
						.99	.98	1.00	.98	.97	.98	.99	1.00	1.02	1.01	1.00	1.00	.99	1.02	1.01	15.2	Middle of run.
						.99	.98	.97	1.00	.98	1.00	.97	1.00	1.02	1.00	.99	1.00	.99	1.00	1.00	15.0	Final
33	20 Nov 62	18	7.5	140	12.5	1.04	1.04	1.00	1.01	1.01	1.01	1.04	1.06	1.06	1.05	1.05	1.05	1.05	1.06	1.05	15.7	Initial
34	28 Nov 62	20	5	135	12.3	1.04	1.02	1.01	1.02	1.01	1.01	1.02	1.04	1.03	1.03	1.02	1.02	1.02	1.03	1.03	15.6	Initial
35	30 Nov 62	20	4	140	11.9	1.06	1.05	1.05	1.05	1.06	1.06	1.06	1.09	1.07	1.04	1.03	1.02	1.03	1.03	1.03	15.9	Initial
						1.06	1.04	1.08	1.04	1.04	1.04	1.02	1.06	1.06	1.09	1.09	1.06	1.04	1.06	1.06	15.8	Final
36	26 Dec 62	15	5.5	140	12.4	1.01	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	.99	15.3	Initial
38	4 Jan 63	32	4.5	150	10.5	1.06	1.04	1.03	1.03	1.04	1.04	1.06	1.06	1.05	1.03	1.03	1.04	1.04	1.04	1.04	15.7	Initial
						1.04	1.02	1.02	1.03	1.02	.99	1.00	1.04	1.06	1.05	1.01	.87	1.01	1.03	1.05	15.3	Final
40	8 Jan 63	30	4.5	155	11.6	1.05	1.04	1.03	1.04	1.05	1.29	1.05	1.05	1.05	1.05	1.04	1.05	1.05	1.05	1.06	16.1	Initial
41	9 Jan 63	15	5	135	12.5	1.05	1.04	1.03	1.03	1.04	1.04	1.03	1.04	1.04	1.02	1.02	1.01	1.02	1.02	1.02	15.7	Initial
[illegible]	9 Jan 63	20	4	135	12.0	1.06	1.02	1.02	1.04	1.01	1.01	1.01	1.02	1.05	1.02	1.02	1.02	1.01	1.01	1.01	15.3	Initial
[illegible]	11 Jan 63	15	5	115	12.3	1.06	1.03	1.04	1.03	1.03	1.03	1.03	1.04	1.03	1.03	1.03	1.04	1.03	1.04	1.03	15.7	Initial
[illegible]	13 Jan 63	20	7	125	11.9	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.05	1.05	1.04	1.04	1.04	1.02	16.0	Initial
47	30 Jan 63	0	0	80	—	1.08	1.06	1.06	1.04	1.06	1.05	1.07	1.06	1.05	1.03	1.07	1.04	1.04	1.05	1.04	16.1	Taken at standard operating pressure

TABLE 5

OPEN CIRCUIT VOLTAGE HISTORY OF MODULE NUMBER 3

Run No.	Date	Max. Amps	Length of Run Hrs.	Module Temp. °F	Operating Volt	Individual Cell Open Circuit Voltage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OCV	Comments
D	1 June 62	45	.5	150	11.7	1.17	1.15	1.14	1.13	1.17	1.09	1.14	1.17	1.19	1.13	1.16	1.16	1.20	1.01	1.07	17.1	Initial - run after construction
17	28 Sept 62	20	5.75	140	13.0	1.06	1.04	1.04	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.05	1.04	1.05	1.05	1.04	15.8	Initial
18	1 Oct. 62	15	1.75	140	13.0	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.10	1.00	1.00	15.2	Initial
19	2 Oct. 62			140		1.20	1.20	1.00	1.20	1.00	1.10	1.10	1.20	1.30	1.20	1.10	1.20	1.20	1.20	1.20	17.4	Initial
		15	3.5	145	12.8	1.03	1.02	1.02	1.03	1.02	1.03	1.04	1.03	1.04	1.03	1.01	1.02	1.03	1.03	1.03	15.4	Final
20	3 Oct. 62					1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.03	1.04	1.04	1.04	1.04	15.5	Initial
		15	8	140	12.7	.86	.88	.90	.90	.90	.90	.90	.92	.91	.90	.90	.90	.92	.90	.90	13.5	Final
21	4 Oct. 62			135		1.02	1.00	1.01	1.00	1.00	1.00	1.00	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.02	15.1	Initial
		21	7.75	140	12.0	1.02	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.01	1.01	1.03	1.02	1.02	15.2	Final
22	8 Oct. 62			85		1.07	1.03	1.04	1.04	1.06	1.05	1.06	1.06	1.06	1.07	1.05	1.05	1.06	1.06	1.05	15.8	Initial - after four days resting during system modification.
				150		1.05	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.04	1.04	1.03	1.03	1.04	1.03	1.04	15.4	Mid-run
		10	7.75	150	13.1	1.05	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.03	1.05	1.04	1.04	15.0	Final
23	9 Oct. 62	20	6.0	150	12.5	1.07	1.05	1.06	1.04	1.05	1.04	1.06	1.05	1.06	1.06	1.04	1.04	1.01	1.05	1.05	15.9	Initial
24	10 Oct. 62	15	1.5	145	12.0	1.08	1.05	1.05	1.06	1.07	1.07	1.07	1.07	1.07	1.07	1.05	1.05	1.07	1.05	1.05	15.5	Initial
25	11 Oct. 62			135		1.07	1.05	1.04	1.04	1.04	1.04	1.04	1.05	1.05	1.06	1.03	1.04	1.07	1.05	1.04	15.6	Initial
		15	7.6	150	12.8	1.03	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.03	1.01	1.01	1.03	1.02	1.02	15.2	Final
26	11 Oct. 62	15	4.3	145	12.4	1.07	1.05	1.06	1.04	1.05	1.03	1.06	1.07	1.06	1.04	1.05	1.05	1.05	1.06	1.05	15.0	Initial
27	12 Oct. 62	20	7.25	105	12.3	.99	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.01	1.01	15.0	Initial
28	12 Oct. 62			140		1.06	1.04	1.05	1.00	.99	1.07	1.06	1.06	1.04	1.19	.99	1.02	1.05	1.05	1.04	15.5	Initial
		20	2.3	150	12.2	1.08	1.05	1.06	1.04	1.00	1.05	1.06	1.05	1.06	1.02	1.04	1.07	1.09	1.08	1.05	16.0	Final
29	15 Oct. 62			75		.85	.67	.80	.65	.70	.71	.69	.52	.44	.61	.40	.73	.51	.25	.36	8.9	Initial - retained OCV after 3 days with gas supply shut off.
				75		1.08	1.04	1.06	1.03	1.04	1.06	1.07	1.07	1.06	1.07	1.05	1.06	1.06	1.05	1.05	15.9	Initial - instantaneous recovery when gas is supplied.
				135		1.08	1.05	1.06	1.06	1.07	1.08	1.09	1.08	1.08	1.08	1.07	1.06	1.07	1.07	1.06	16.1	Initial - module at operating temperature
		20	4.25	150	12.2	1.04	1.02	1.02	1.00	1.01	1.06	1.06	1.06	1.06	1.04	1.03	.99	1.04	1.04	1.04	15.5	Final
30	17 Oct. 62			130		1.07	1.05	1.06	1.04	1.07	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.06	1.06	16.0	Initial
				145		.98	1.02	1.03	1.04	1.05	1.05	1.04	1.03	1.02	1.02	1.03	1.03	1.03	1.03	1.03	16.0	Mid-run
		25	10.0	145	11.5	1.02	1.02	1.01	1.00	1.02	1.03	1.03	1.03	1.03	1.03	1.02	1.01	1.04	1.00	1.03	15.2	Final
31	19 Oct. 62			75		.15	.34	.42	.43	.41	.18	.04	.00	.08	.01	.01	.20	.03	.19	.17	2.7	Initial - retained OCV
				130		1.02	1.03	1.03	1.02	1.04	1.04	1.04	1.04	1.04	1.05	1.03	1.03	1.05	1.05	1.04	15.6	Initial - instantaneous recovery
		25	3.5	150	11.2	1.05	1.00	.98	.99	1.01	1.05	1.05	1.05	1.05	1.05	1.04	1.04	1.05	1.03	1.04	15.3	Final
47	30 Jan. 63	0	0	80	-	1.04	.98	1.01	1.00	1.07	1.07	1.07	1.07	1.04	1.09	1.11	1.10	1.28	1.09	1.34	16.6	Taken at standard operating pressure.

TABLE 6

OPEN CIRCUIT VOLTAGE HISTORY OF MODULE NUMBER 4

Run No.	Date	Max Amps.	Length of Run Hrs.	Mod. Temp. F	Operating Volt.	Individual Cell Open Circuit Voltage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OCV	Comments
E	6 June 62	41	1/2	150	12.1	1.21	1.20	1.17	1.07	1.07	1.06	1.07	1.19	1.12	1.07	1.04	1.10	1.02	1.20	1.23	16.8	Initial
1	31 July 62	18	4	110	-	1.06	1.06	1.06	1.06	1.05	1.06	1.07	1.06	1.07	1.06	1.06	1.06	1.05	1.04	1.08	15.9	Initial
				150	-	1.04	1.04	1.05	1.04	1.05	1.06	1.07	1.06	1.07	1.06	1.06	1.06	1.05	1.06	1.08	15.9	Final
3	15 Aug. 62	15	2.4	130	13.5	1.02	1.01	1.02	1.02	1.01	1.03	1.01	1.03	1.03	1.04	1.04	1.02	1.02	1.02	1.01	15.3	Initial
4	16 Aug. 62	30	6	132	12.1	1.04	1.04	1.04	1.03	1.03	1.04	1.01	1.02	1.03	1.03	1.03	1.01	1.01	1.01	1.01	15.4	Initial
5	17 Aug. 62	35	7.5	135	11.8	.96	.97	.98	.99	.99	1.01	1.01	1.01	1.02	1.02	1.00	1.00	1.00	1.00	1.00	15.0	Initial
6	21 Aug. 62	16	4	105	12.3	1.01	.99	1.00	1.00	1.00	.99	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	15.0	Initial
7	22 Aug. 62	16	6.5	125	12.0	.99	.98	1.00	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	.99	1.01	1.01	1.00	15.0	Initial
8	23 Aug. 62	20	6	135	12.4	1.03	.99	1.01	1.01	1.00	1.00	1.00	1.01	1.01	1.01	1.01	.99	1.01	1.01	.99	15.1	Initial
10	27 Aug. 62	7	1	88	13.2	1.04	1.01	1.02	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.01	15.3	Initial
11	13 Sept 62	19	4	150	12.6	1.04	1.03	1.02	1.03	1.04	1.03	1.02	1.03	1.03	1.02	1.02	1.00	1.01	1.02	1.00	15.3	Initial
13	17 Sept 62	10	5	132	12.1	.96	1.04	1.00	1.02	.98	.98	1.04	1.00	1.00	1.00	1.00	1.04	1.02	1.02	1.00	15.1	Initial
14	18 Sept 62	13	8	120	12.0	1.06	1.06	1.02	1.06	.96	.96	.98	1.00	1.04	1.00	1.02	.98	1.00	1.01	1.02	15.2	Initial
15	19 Sept 62	18.5	6	70	11.5	1.05	1.04	1.02	1.05	1.02	1.03	1.02	1.04	1.04	1.02	1.02	1.02	1.02	1.02	1.03	15.4	Initial

TABLE 7

OPEN CIRCUIT VOLTAGE HISTORY OF MODULE NUMBER 4A

Run No.	Date	Max. Amps	Length of Run Hrs.	Module Temp. F	Operating Volt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OCV	Comments
						Individual Cell Open Circuit Voltage																
36	26 Dec 62	15	5	150	12.5	.94	1.08	1.06	1.05	1.04	1.06	1.06	1.05	1.06	1.02	1.07	1.03	1.03	1.03	1.04	15.8	Initial
37	2 Jan 63	41	3.5	155	11.9	1.07	1.04	1.06	1.06	1.04	1.05	1.04	1.05	1.06	1.06	1.07	1.07	1.06	1.06	1.06	15.9	Initial
39	7 Jan 63	30	5	155	11.5	1.08	1.08	1.07	1.08	1.07	1.07	1.08	1.08	1.08	1.27	1.08	1.07	1.07	1.07	1.07	16.5	Initial
						1.06	1.06	1.06	1.01	1.01	1.07	1.07	1.06	1.07	1.00	1.07	1.05	1.07	1.06	1.06	16.0	Final
41	9 Jan 63	15	5	135	12.4	.94	1.05	1.03	1.01	1.00	1.02	1.02	1.01	1.02	.99	1.04	.98	.96	.98	1.01	15.2	Initial
42	9 Jan 63	20	4	135	12.0	.91	1.04	1.01	.99	.98	1.02	1.00	.99	1.02	.99	1.04	.99	.98	.98	1.01	15.1	Initial
43	10 Jan 63	30	4	150	11.6	.94	1.06	1.04	1.04	1.03	1.05	1.05	1.04	1.06	1.03	1.07	1.03	1.02	1.02	1.04	15.7	Initial
44	11 Jan 63	15	5	110	12.3	.95	1.04	1.01	1.01	1.03	1.01	1.03	1.01	1.03	1.01	1.03	1.00	1.00	1.00	1.00	15.5	Initial
45	13 Jan 63	20	7	115	11.4	.89	1.06	1.03	1.02	1.02	1.03	1.02	1.02	1.04	1.02	1.06	1.03	1.01	1.01	1.01	15.5	Initial
46	17 Jan 63	28	6	130	11.3	1.02	1.01	1.01	1.01	1.02	1.01	1.01	1.02	1.04	1.01	1.02	1.01	1.00	1.00	1.01	15.2	Initial
47	30 Jan 63	0	0	80	-	.90	1.08	1.05	1.07	1.08	1.06	1.09	1.08	1.09	1.07	1.00	1.07	1.07	1.04	1.04	16.0	Taken at standard operating pressure

TABLE 8

Comparison of Open Circuit Voltages During Operation

		Open Circuit Voltage Initial	Mid-Run	Final
Run 22	Module 1	16.3	15.7	15.6
	2			
	3	15.8	15.4	15.0
Run 30	Module 1	16.0	15.5	15.4
	2			
	3	16.0	16.0	15.2
Run 32	Module 1			
	2	15.8	15.2	15.0
	3			

TABLE 9

Comparison of OCV at Beginning, Mid-term and Completion of Testing

Run No.	A	B	D	E	15	16	17	32	37	47
Date	5-4-62	5-5-62	6-1-62	6-6-62	9-19-62	9-21-62	9-28-62	11-19	1-2-63	1-30-63
Mod. 1	15.86					15.8				15.5
Mod. 2		17.08						16.1		16.1
Mod. 3			17.13				15.8			16.6
Mod. 4				16.82	15.41					
Mod. 4A									15.9	16.0

TABLE 10

Temperature of Five Points on the Surface of a Fuel Cell

Time	Current Amps	Temperature on Cell Surface — Thermocouple Position A	B	C	D	E
1600	42	156	156	156	156	157
1800	41	164	165	164	165	163
2000	40	156	156	156	156	156
2200	40	156	157	156	157	156
2400	40	153	153	153	153	152

TABLE 11

Temperature of Cells within a Module

Run No.	Mod. No.	Cell Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
26	1	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155
	3	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
48	1	135	135	135	135	135	135	133	133	133	133	133	133	134	133	135
	2	145	146	145	145	145	145	146	144	144	145	145	145	145	146	145
	3	150	150	150	150	149	149	149	150	149	150	150	150	150	149	149
	4A	148	148	148	419	150	150	149	149	149	150	150	150	148	148	149

1

TABLE 12

Date	Run No.	Mod. No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp.	Remarks
4 May 1962	A							
		1	44	0.5	12.0		150	Initial Check Out
21 May 1962	B							
		2	42	0.25	11.8		150	Initial Check Out Second Check out { Cell #2 was bad and need replacing
22 May 1962	C							
		2	41	0.25	12.1		150	
1 June "	D							
		3	45	0.25	11.7		150	Initial Check Out
6 June 62	E							
		4	41	0.5	12.1		150	Initial Check Out
31 July 62	1							
		4						
2 Aug. 62	2							
		4	10	0.5	13.2		138	First Run on Automatic Control
			13	0.5	13.1		140	
			14	0.5	12.9		140	
			15	1.5	13.2			
			14	1.25	13.1			
			10	1.0	13.3			
			15	0.5	13.1		145	
			20	1.0	12.4			
			21.5	0.5	12.5			
			23.	0.25	12.5			The test was cut short due to
			24.		12.5			inadequate gas flow.control.
15 Aug. 62	3							
		4	7.0	0.25	13.5		130	
			10.0	0.75	13.2		140	
			15.0	1.50	12.8		143	
16 Aug. 62	4	4	10	1.0	13.1		132	
			15	1.25	12.6		148	
			20	1.0	12.5		154	Differential pressure regulator
			23.5	0.5	12.4		154	is not performing properly. It
			26	0.5	12.4			fails to maintain an adequate
			27.5	0.5	12.3			pressure when demand for gas
			28	0.25	12.2			increases.
			30	0.75	12.1			

Date	Run No.	Mod. No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp.	Remarks
17 Aug 62	5	4	15	0.25	12.9		140	
			21	1.0	12.6		150	
			25	0.25	12.5			
			26	0.25	12.5			
			28	0.75	12.1		140	The module is running under manual
			30	0.75	12.3			control and performing very well.
			31	0.25	12.1		150	
			20	0.75	12.5		140	
			21	0.5	12.6			
			35	1.0	11.8		155	
			30	0.5	12.1		160	
			10	1.25	13.2			Test Stopped
21 Aug 62	6	4	10	1.5	13.2		140	Automatic Control
			13	0.25	12.3			
			15	0.25	12.8			
			16	2.0	12.7		144	
22 Aug 62	7	4	15		12		135	
					12.9		150	The module has gone through a drying cycle.
					12.8			System is perating on auto. control
				2.25	12.5			Wetting cycle
			16		12.8		135	Drying cycle
					12.9		140	
					13.0		143	
					12.9		150	Wetting cycle
					12.7			
				3.75	12.5			Entire run in automatic control
23 Aug 62	8	4	16		12.9		135	
				1.50	12.7		145	
			20		12.4		140	
					12.5		145	
					12.6		150	
					12.5			
					12.7			

Date	Run No.	Mod. No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp.	Remarks
continued 23 Aug 62	8							
		4		2.0	12.6			
			5		13.7		130	Reduce to 5 amps during lunch hour
				1.0	13.7		140	
			20		12.6		150	Return to 20 amps for remainder of test
				1.5	12.3			
24 Aug 62	9							
		4	5		13.4		135	This is a variable amp run to test the response of the system and reaction of the modules.
				1.0	13.6		150	
			10		13.0			
				1.75	13.2			
			5	0.5	13.6			
			10	0.25	13.2		145	
			30		10.9			
				0.75	11.6		150	
			24	0.25	12.0		160	
			10	1.5	13.0		145	
			20	1.0	12.1		150	
			10	0.5	12.8			The module responded well but the system is too slow - it requires too many adjustments before it catches up.
27 Aug 62	10							
		4	7	0.25	13.2		89	Run stopped because of pump failure.
13 Sept 62	11							
		4	5	1.0				A new recirculation system has been installed - this test is run to check it out.
			10	.5	12.6			
			19	1.25				The entire system is performing very well.
14 Sept 62	12							Load applied while temp is 75°F - heating pads are also on. The module was up to 150°temp within 1.75 hrs.
		4	8		12.5			
				0.5	12.7			
			5	2.0	13.5			
			10	1.25	13.0			
			5	1.0	13.0			
			15	0.25	12.1			
			16	0.25	12.2			

Date	Run No.	Mod. No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp.	Remarks
17 Sept 62	13							
		4	10	0.25	12.1		132	
			5	4.00	12.8		130	
					13.2		135	
					13.3			
18 Sept 62	14							
		4	5	1.0	13.3		130	Rotometers have been changed to try and increase their sensitivity and possibly accuracy.
			8		12.8		140	
					12.9		135	
				1.0	13.0		135	Several solenoids are not working properly.
			10	1.0	12.7			
			13		12.4		140	
					12.2			
					12.1			
				4.75	12.0			
19 Sept 62	15							
		4	10		11.2		75	
				0.5	11.6		105	
			11		11.9		120	
					12.1		135	
				1.0	12.0		139	
			15		11.3		140	
					11.5		135	
				1.0	11.8		140	
			16	0.5	11.8		142	
			17	0.5	11.6		144	
			18		11.7		150	
				1.25	11.7		165	
			20	0.75	11.5		155	
			10	0.5	12.5		150	
21 Sept 62	16							
		4	5		13.4		142	
				1.0	13.0		145	
			10	0.5	11.8		148	
			15	0.5	12.6		148	
			20	2.5	12.6		150	
			25		12.6		152	
					11.8			
					11.9			
				1.25	12.1			
			23	1.0	12.2		145	

Date	Run No.	Mod. No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp.	Remarks
28 Sept 62	17							
		1&3	10			27.5	145	
				2.5		27.5	148	
			15			27.0	135	
				2.0		28	150	
			20	1.0		26		
1 Oct 62	18							
		1&3	10	1.25		26	145	
			15	0.50		26	150	
2 Oct 62	19							
		1&3	10			26.7	145	
				1.25		26.4	150	
			15			25.1	155	
				1.0		26	150	
3 Oct 62	20							
		1&3	10	0.25		26.2	145	
			12	0.25		26.0	150	
			15	0.25		25.6	150	
			10	1.0		26.2	145	
			15			25.7	150	
						25.4		
						25.3		
						25.0		
				2.0		25.2	145	
			10	3.25		25.5		
4 Oct 62	21							
		3	12	0.25	12.5		135	
		1&3	12	0.25		25.5	145	
			15	1.75		25.3	145	
			16	1.50		25.3		
			17			25.1	147	
				0.50		25.8	144	
			18			25.2	150	
						25.1	150	
				1.25		25.0		
			19	1.25		24.7		
			21			24.3	155	
				0.25		24.5		

Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp	Remarks
8 Oct 62	22							
		1&3	10			26.5	145	
						26.0	150	
						25.9	145	
						25.8	150	
				5.75		25.7		
9 Oct 62	23							
		1&3	20			24.9	150	
						25.1		
				4.5		24.6		
			10			26.0	150	
						26.2		
						25.7		
				2.25		25.5		
10 Oct 62	24							
		1&3	11			25.6	150	
						25.7	150	
						25.5	150	
				1.0		25.0	150	
			15	0.25		25.0	150	
11 Oct 62	25							
		1&3	15	0.25		25.3	135	Mod. #1 shut down - control box not working properly.
		3	15	0.50	12.2		150	
		3	5	1.0	12.9		150	
		3	10	4.25	12.7		150	
11 Oct 62	26	1&3	11.5	.50		25.5	145	
			10	1.25		25.7	140	
			13.0	.25		25.3	140	
			15.0	2.75		24.7	145	
12 Oct 62	27	1&3	15.0	1.0		25.7	130	
			20.0	4.0		24.3	145	
						23.9	150	
						24.4	150	

Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp	Remarks
12 Oct 62	28	1&3	20.0	0.25		24.8	143	
		3	5.0	0.50	12.5		145	Mod.#1 on OCV, Mod#3 started at 5 amps
			10.0	1.00	12.8		148	to correct.moisture behavior.
			15.0	0.25	12.6		150	
			20.0	0.25	12.2		150	
15 Oct 62	29	1&3	20.0	2.75		24.6	150	
						24.5	150	
						24.7	150	
						24.0	150	
15 Oct 62	30	1&3	15.0	2.0		25	140	
						25.4	145	
			20.0	0.25		24.7	155	
			25.0	1.75		23.5	160	
						23.1	160	
						22.5	165	Load cut;cell htg. up - Temp con-
			15.0	0.25		25.0	150	trollers acting up. Repairs made.
			20.0	.75		24.0	150	Modules loaded down again. Broken
			22.0	.50		23.9	150	Micro Switch.
			24.0	.50		23.9	150	
			25.0	3.50		23.5	150	
						23.0	150	
						22.6	150	
						22.0	150	
						22.6	150	
19 Oct 62	31	1&3	5.0	0.25		25.9	125	
			15.0	0.75		24.9	140	
			20.0	1.0		24.0	145	
			22.0	.50		22.6	150	
			24.0	.50		22.1	150	
			25.0	.50		22.3	155	

Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp	Remarks
19 Nov 62	32	1&2	10.0	17.0		26.6	135	Started at 10 amps for 12 hrs run or better.
						26.3	135	Down for 10 min. Thermo-switch trouble
						25.9	140	
						25.4	140	
						25.1	135	
						25.3	140	System shut down large H_2,Leak apparent
						25.8	115	
						25.4	130	
						24.7	135	Flow trouble - system down for 2 hrs.
						25.0	140	
						24.9	150	
20 Nov 62	33	1&2	10.0	0.75		25.5	130	
			15.0	1.5		25.7	135	
			18.0	1.0		25.0	140	
						24.6	140	
			10.0	.50		24.2	140	Modules are on dry side - load cut to balance system.
						24.6	140	
			16.0	1.5		23.5	140	
						23.4	140	
			18.0	.50		23.6	140	
			20.0	1.0		23.4	140	Shut down for 1 Hr.,control box trouble
			10.0	1.25		25.5	135	
			13.0	1.0		25.2	140	
			15.0	1.0		24.8	145	
			17.0	3.0		24.4	145	
						23.7	145	
						23.4	145	
			19.0	.50		22.3	145	Modules are dry - Hard to control

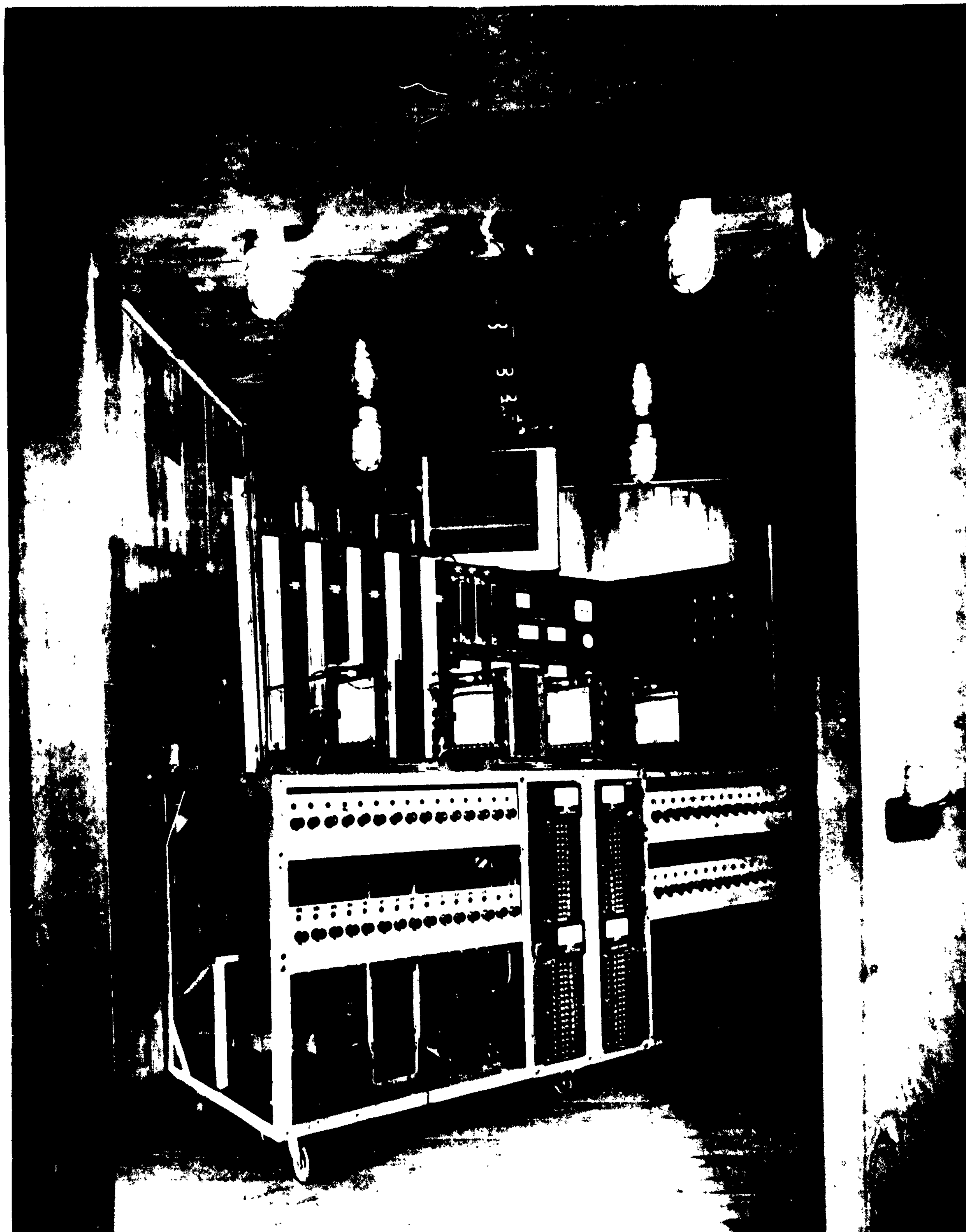
Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp	Remarks
28 Nov 62	34	1&2	18.0	1.75		24.5	135	
						24.2	140	
			20.0	2.75		23.8	140	
						23.6	135	
						23.9	135	
			16.0	.75		23.6	135	
			6.0	.75		25.5	130	
30 Nov 62	35	1&2						
			30.0	.25		22.6	145	
			20.0	.50		22.9	140	
			21.0	3.0		23.0	140	
						23.2	140	
						22.8	140	
			20.0	.25		22.5	150	
26 Dec 62	36	1-2-4A	10.0	2.0		38.2	150	O_2 Flow rather critical in operation of 3 modules.
						39.0	150	
						38.5	150	First operation with new valving in system.
			15.5	1.0		36.5	150	
						37.0	150	
			15.0	2.5		38.0	150	
						37.0	150	
						38.0	150	
2 Jan 63	37	4A	10.0	.50	13.2		135	High amp run on new module
			20.0	.50	12.2		140	
			30.0	1.25	12.0		150	
			37.0	1.00	11.9		150	
					12.0		150	
			41.0	2.25	11.8		150	
					11.7		150	
					11.9		150	
					11.6		150	

Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Module Temp.	Remarks
4 Jan 63	38	2	30.0	1.5	11.6		145	Hi amp run on Mod. No. 2
					11.2		150	Voltage control box not working properly
					11.0		150	
			32.0	3.0	10.6		160	
					10.2		150	
					10.5		145	
					10.0		150	
					9.9		150	Test shut down - Control box went bad
7 Jan 63	39	4A	17	0.25	12.3		120	
					12.5		135	
			25	.25	12.0		140	
					12.2		155	
			32	.25	11.5		165	
					11.5		165	Test shut down. Thermoswitch not operating properly.
			34	.50	11.5		140	
			25	.50	12.1		155	
			31	.50	11.8		160	High temp. on modules badly hampers controlled run.
			35	2.00	11.3		165	
					11.1		165	
					11.2		170	
					11.0		170	
					10.8		170	Heating controls not operating properly - shut down.
8 Jan 63	40	2	20	.25	12.4		130	
			26	.75	12.1		135	
					11.8		150	
					11.5		145	
			28	.25	11.3		155	
					11.5		150	
			30	3.5	11.5		155	
					11.6		160	
					11.5		160	
					11.6		160	

Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Voltage Temp.	Remarks
9 Jan 63	41	1-2-4A	10.0	1.25		39.0	140	1st test with controlled outside temp.
						38.5	140	3 modules down 15 mins, busted spring
						38.9	140	on scanner.
			16.0	4.0		38.2	135	125°F
						37.4	135	
						36.6	140	
						36.7	140	
9 Jan 63	42	1-4A	20	4.0		24.6	135	2nd test controlled outside temp.
						24.3	135	2 modules 125°F
						23.9	135	
						23.7	135	
						24.1	140	
						23.9	140	
						24.0	140	
						24.0	140	
10 Jan 63	43	4A	26	.50	12.2		135	3rd test controlled outside temp.
					11.9		140	1 module 125°F
			32	.75	11.3		145	
					11.1		145	
			30	2.25	11.3		145	
					11.5		145	
					11.4		150	
					11.2		145	
					11.4		150	
					11.2		150	
					11.4		150	
11 Jan 63	44	1-2-4A	16.0	5.0		36.8	122	4th test controlled outside temp
						37.3	120	3 modules 30°F
						36.9	110	
						36.5	110	
						35.6	100	
						35.4	100	
						35.6	95	
						36.1	100	
						36.3	115	
						36.8	115	
						36.5	120	
						36.2	125	
						36.2	115	

Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Voltage Temp.	Remarks
13 Jan 63	45	2-4A	16.0	0.25		25.1	125	5th test controlled outside temp.
			20.0	7.0		24.8	115	2 modules
						24.2	110	30°F
						23.9	105	
						23.6	95	Condensation on H_2 inlet. Flowmeter
						23.2	95	indicates moist gas returning to module
						23.4	115	after recirculation.
						23.1	105	
						23.4	95	
						23.2	115	
						23.9	135	
						24.0	135	
17 Jan 63	46	4A	22.0	0.25	12.0		135	6th test controlled chamber temp.
			30.0	1.0	11.5		130	34°F
			34.0	1.25	11.2		125	
					11.1		130	1:00 pM chamber temp. 31°F
					11.0		135	1:15 pm chamber temp. 30°F
			26.0	.25	11.0		135	1:35 " " " 26°F
			30.0	.50	11.1		125	1:55 " " " 22°F
					10.8		130	2:15 " " " 16°F
			25.0	2.5	11.6		130	2:30 " " " 14°F
					11.5		130	
					11.4		130	Solenoids appear to have frozen on
					11.3		125	about 5 or 6.cells at 14°F. Test shut down
					11.2		120	
					10.7		115	
30 Jan 63	47	1-2-3-4A						Individual cell reactance OCV test of gas pressure from 0#-10# and 10#-0#

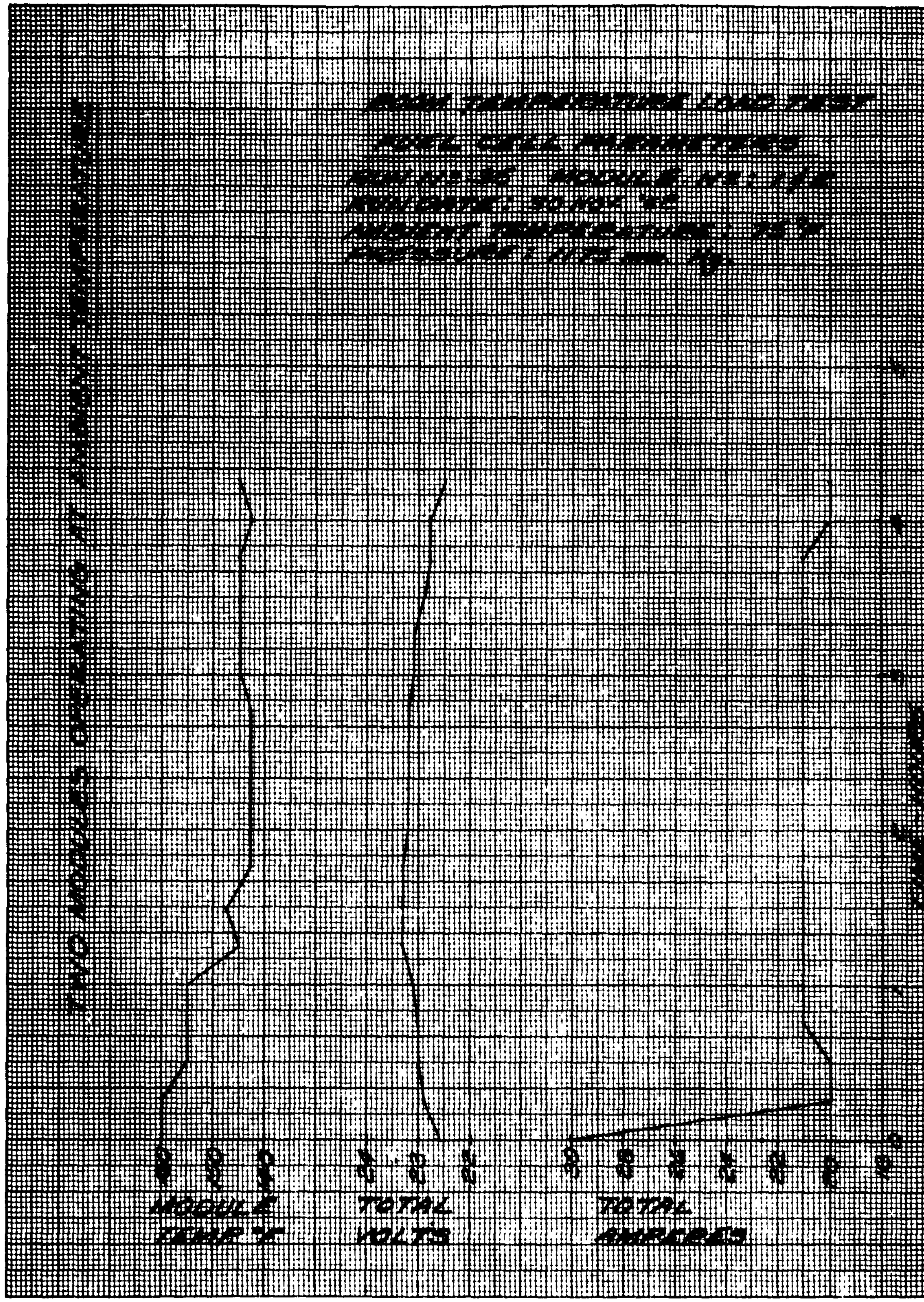
Date	Run No.	Mod No.	Load Amps	Load Duration Hours	Module Voltage	System Voltage	Voltage Temp.	Remarks
30 Jan 63	48	1-2-3 -4A	10.0	1.0		50.1	145	Ambient running conditions
						49.8	145	
			14.0	.5		48.3	135	
						48.2	140	
						48.4	140	
			15.0	4.75		49.2	140	
						49.5	140	
						49.1	135	
						49.0	135	
						48.4	140	
						48.6	140	



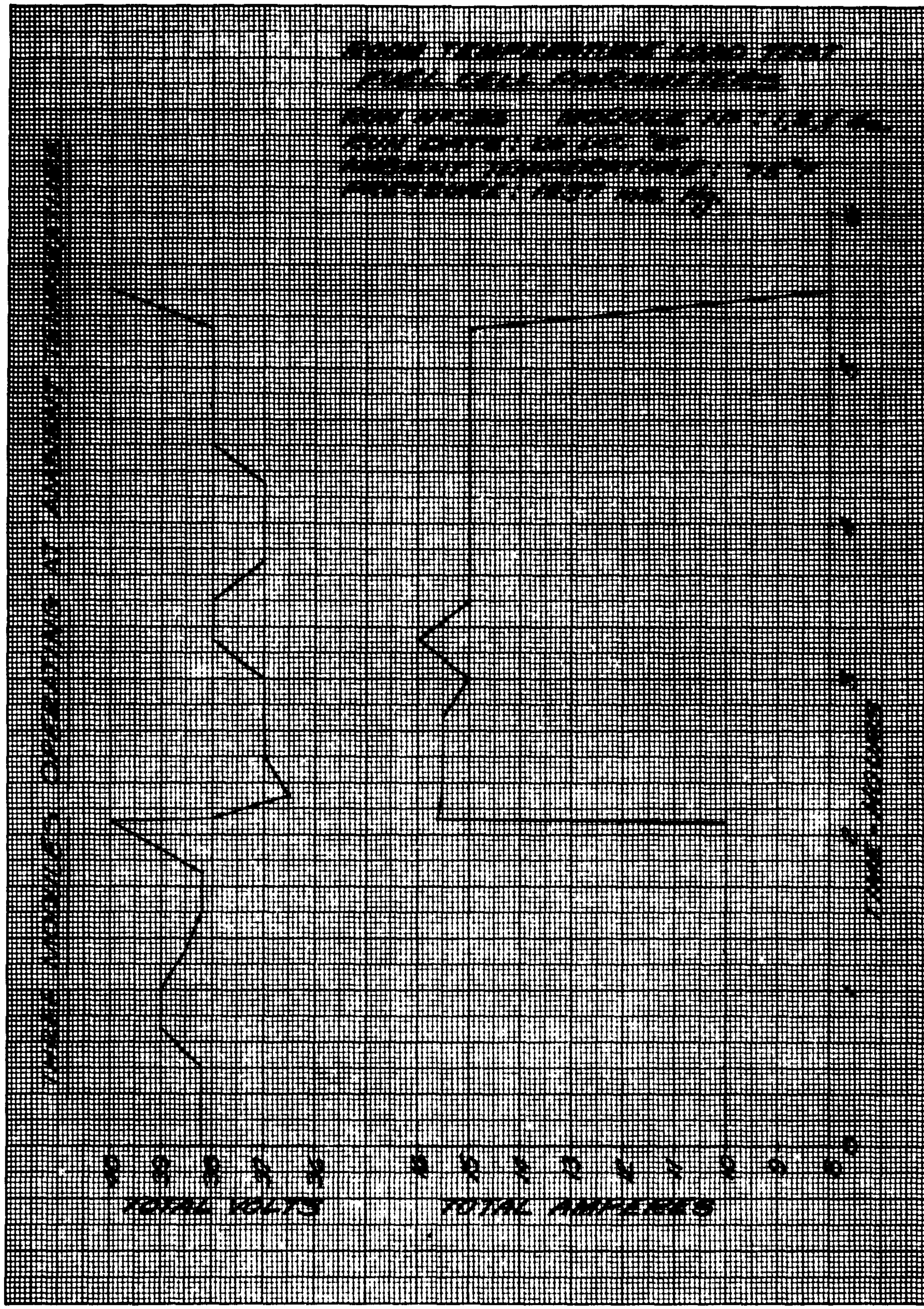
ALLIS-CHALMERS

DOFL power pack & cabinet

Fig. 1



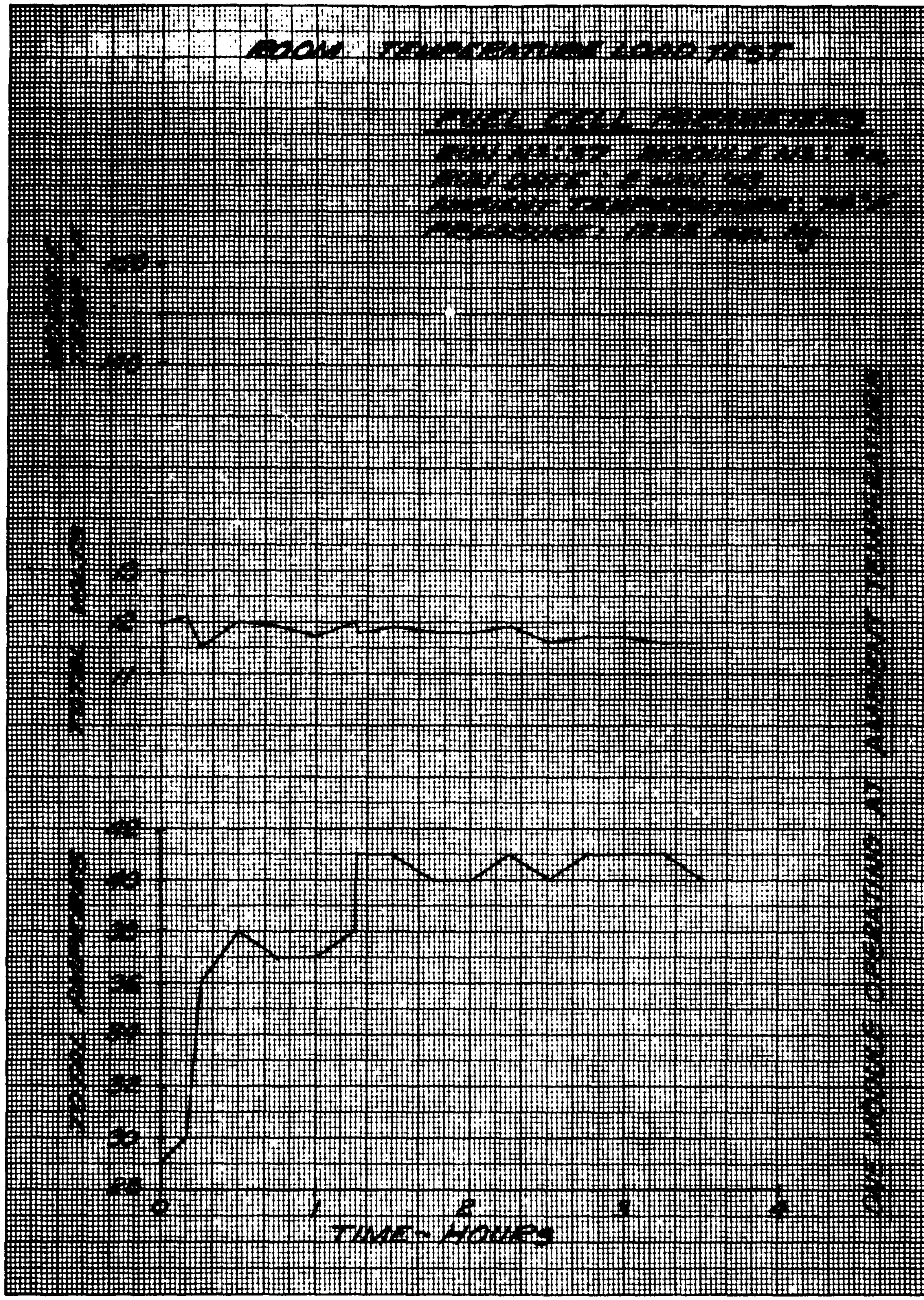
S.A.O.S.
ALLIS-CHALMERS MFG. CO. FIG. 2 2-9-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG.CO.

FIG. 3

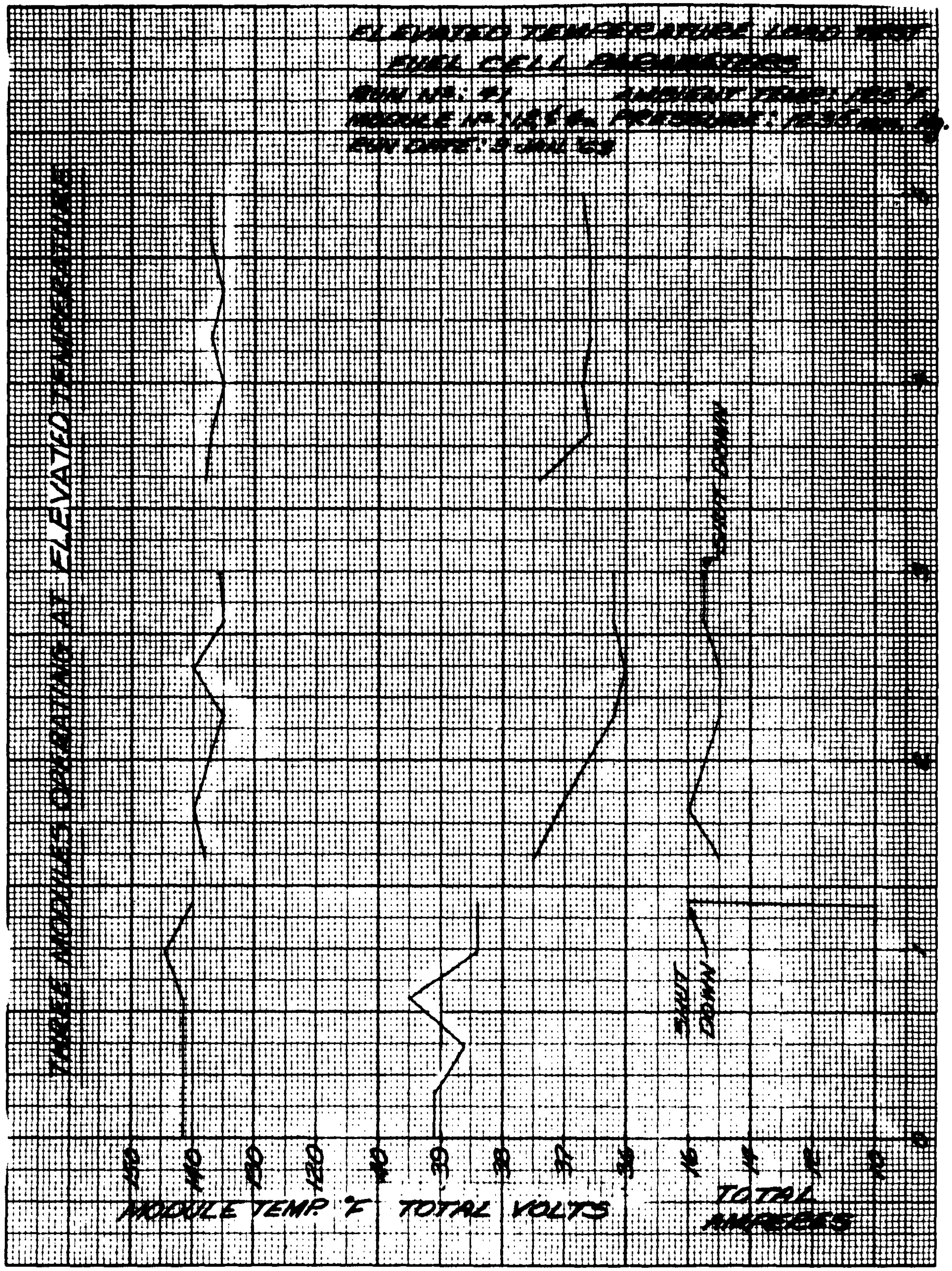
2-9-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 4

2-9-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG.CO. FIG.5 2-9-63 J.H.

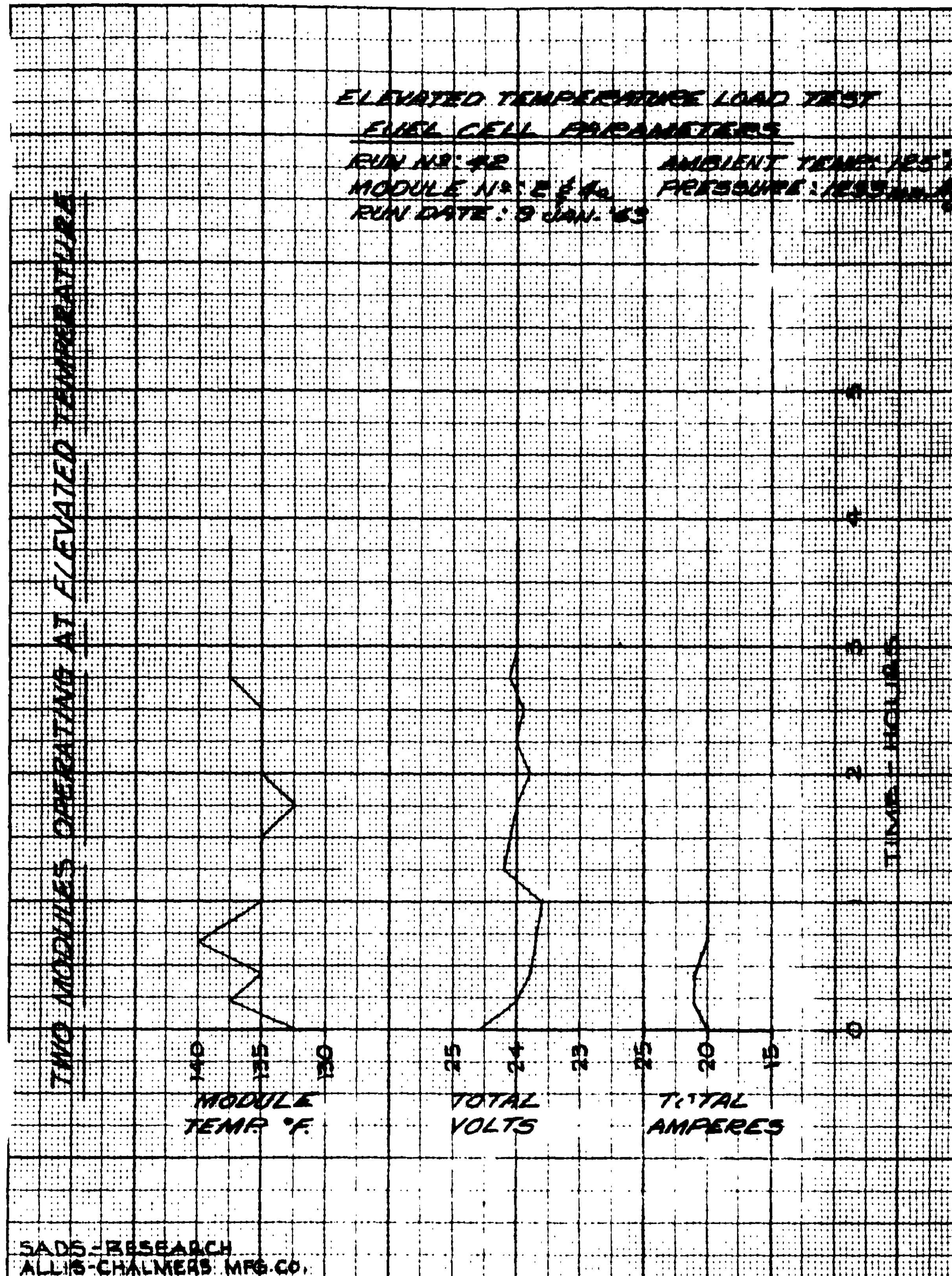
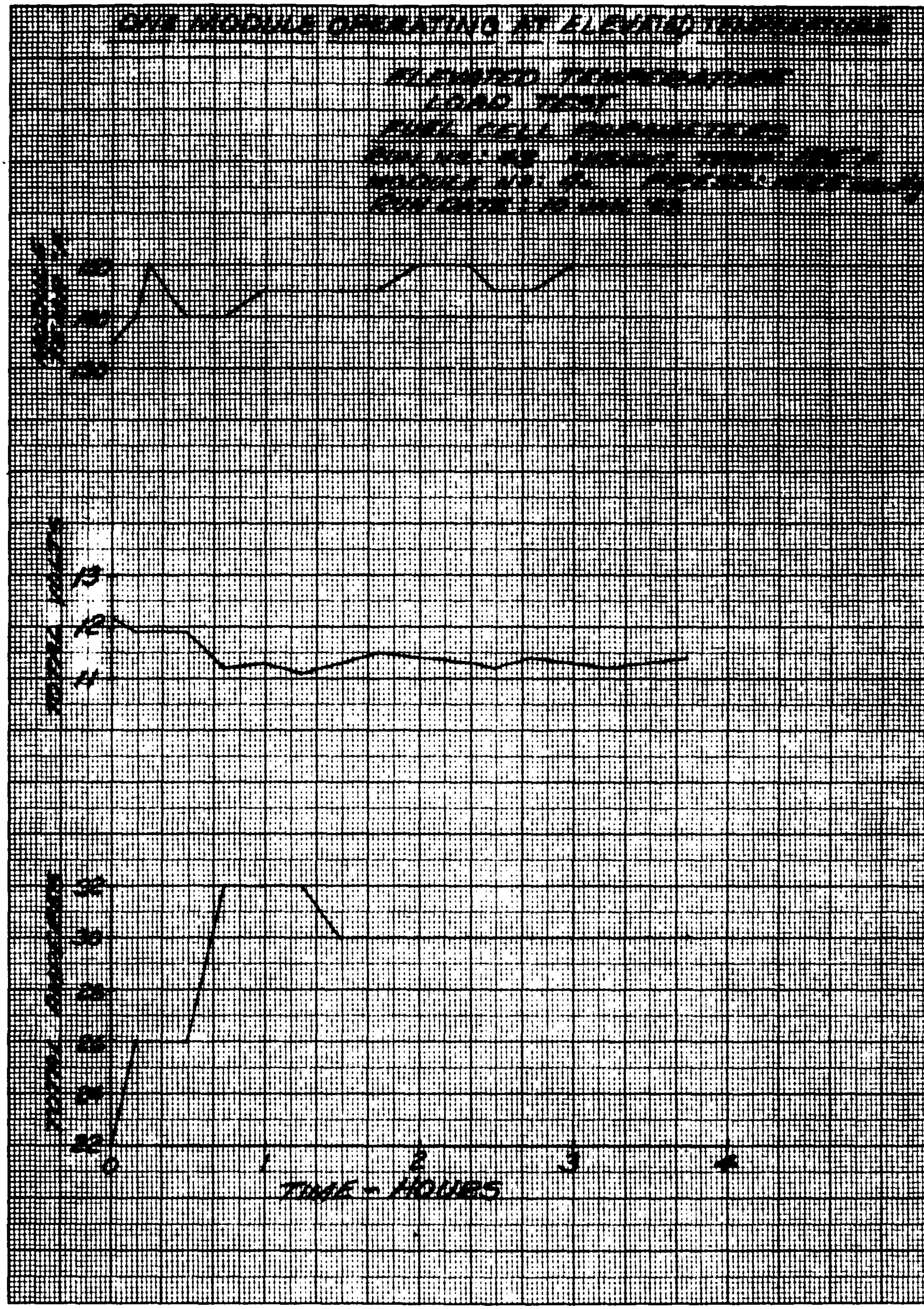

ELEVATED TEMPERATURE LOAD TEST
FUEL CELL PARAMETERS
RUN No: #2
AMBIENT TEMP:
MODULE No: E #4
PRESSURE:
RUN DATE: 9 JAN. '63
TWO MODULES OPERATING AT ELEVATED TEMPERATURE
TIME - HOURS
0
1
2
3
4
5
140
135
130
MODULE
TEMP °F
25
24
23
TOTAL
VOLTS
25
20
15
TOTAL
AMPERES
SADS-RESEARCH
ALLIS-CHALMERS MFG. CO.

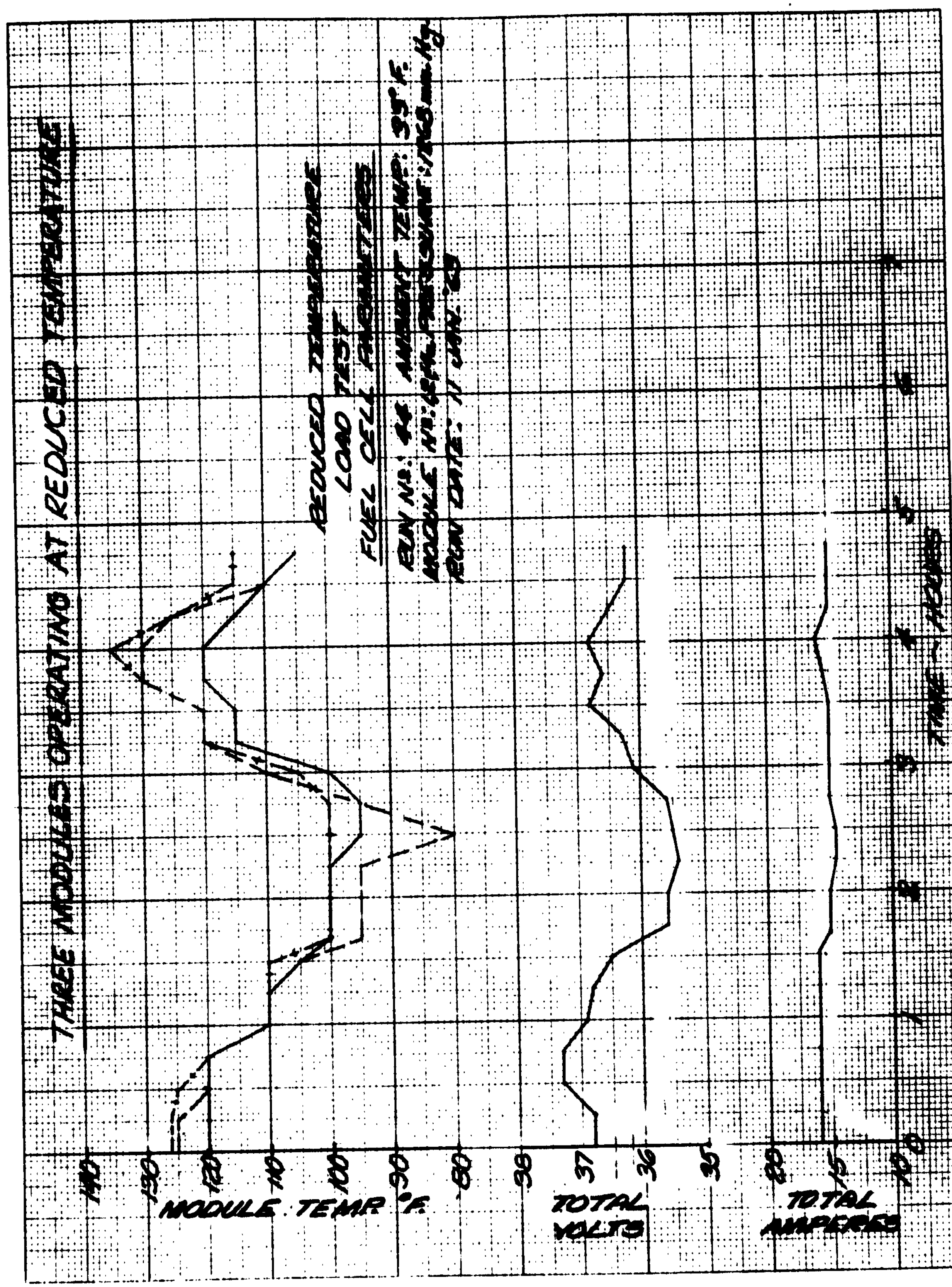
FIG. 6



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 7

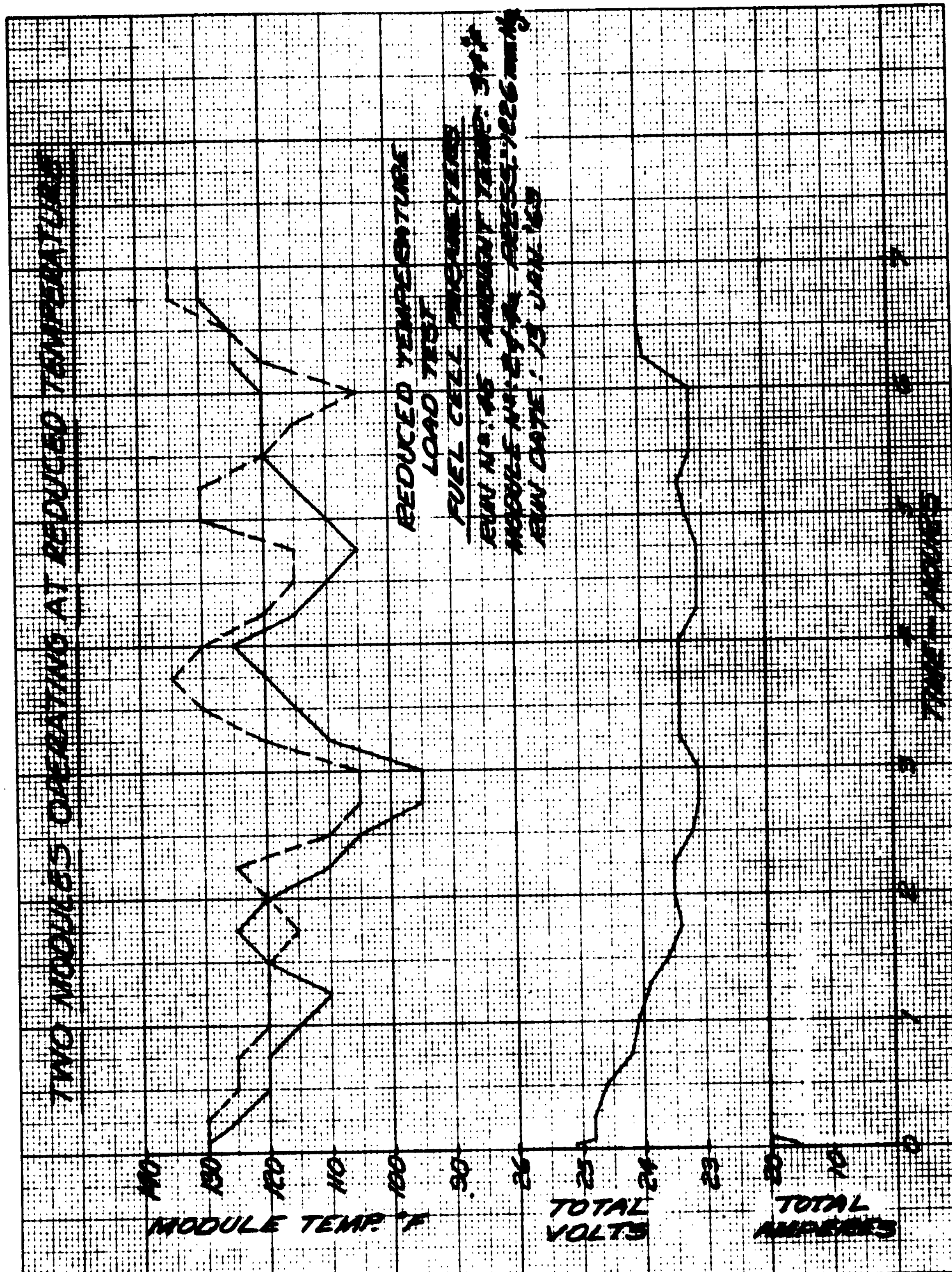
2-9-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 8

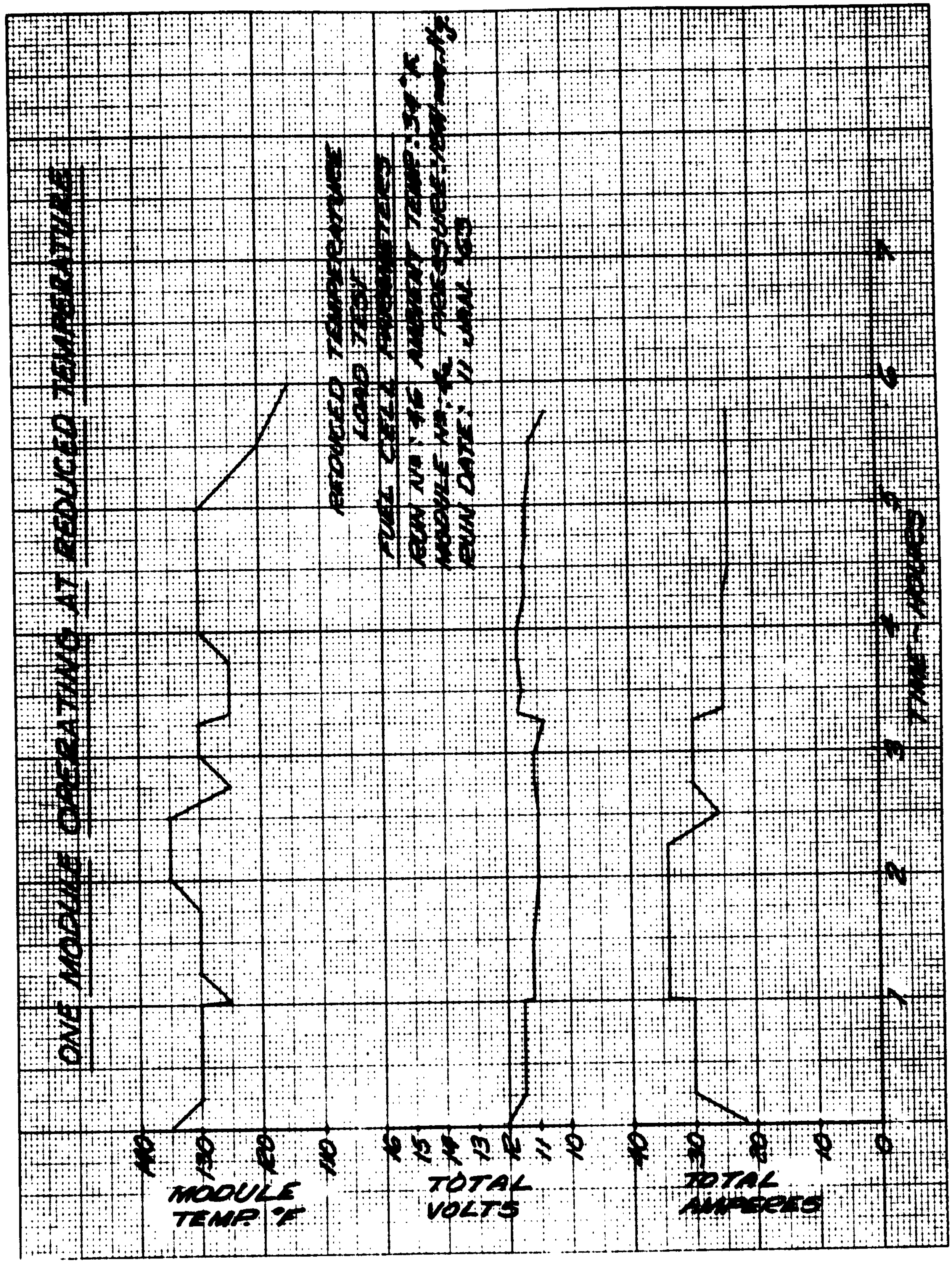
2-8-63 J.H.



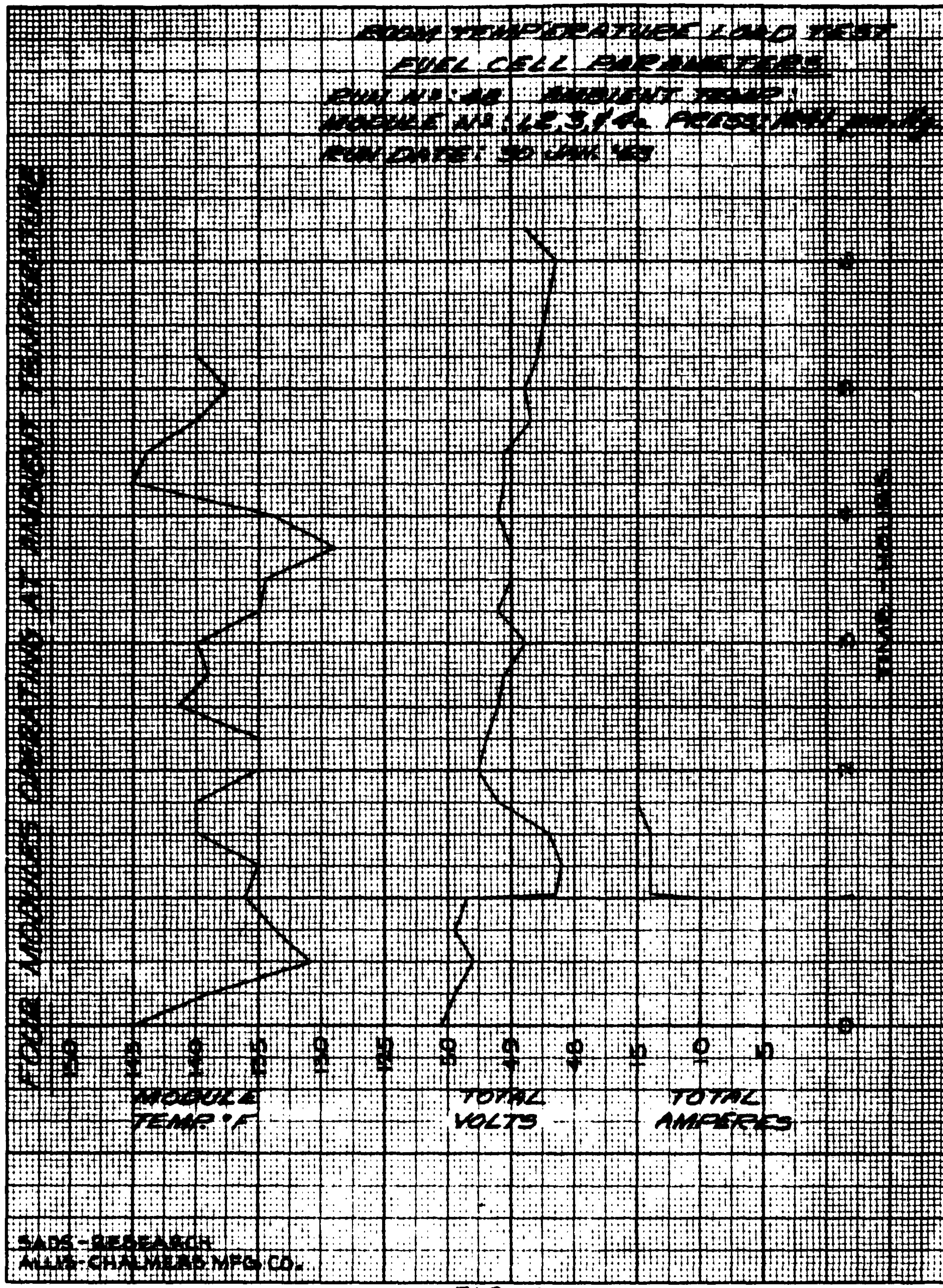
S.A.D.S.
ALLIS-CHALMERS MFG.CO.

FIG. 9

2-8-63 J.H.

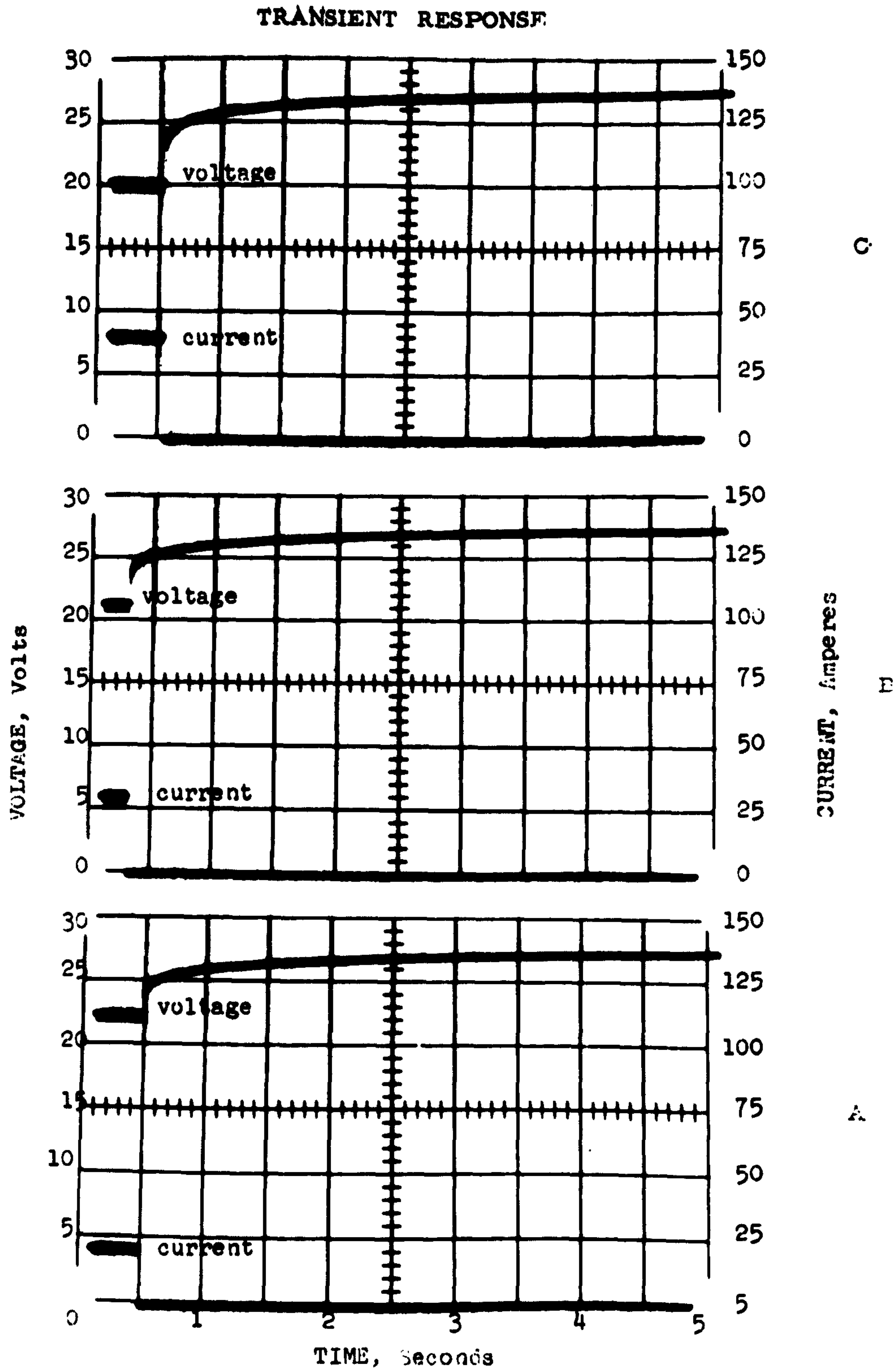


S.A.D.S.
ALLIS-CHALMERS MFG.CO. FIG.10 2-8-63 J.H.



ROOM TEMPERATURE LOAD TEST
FUEL CELL PARAMETERS
MODULE TEMP °F
TOTAL VOLTS
TOTAL AMPERES
SADS-RESEARCH
ALLIS-CHALMERS MFG. CO.

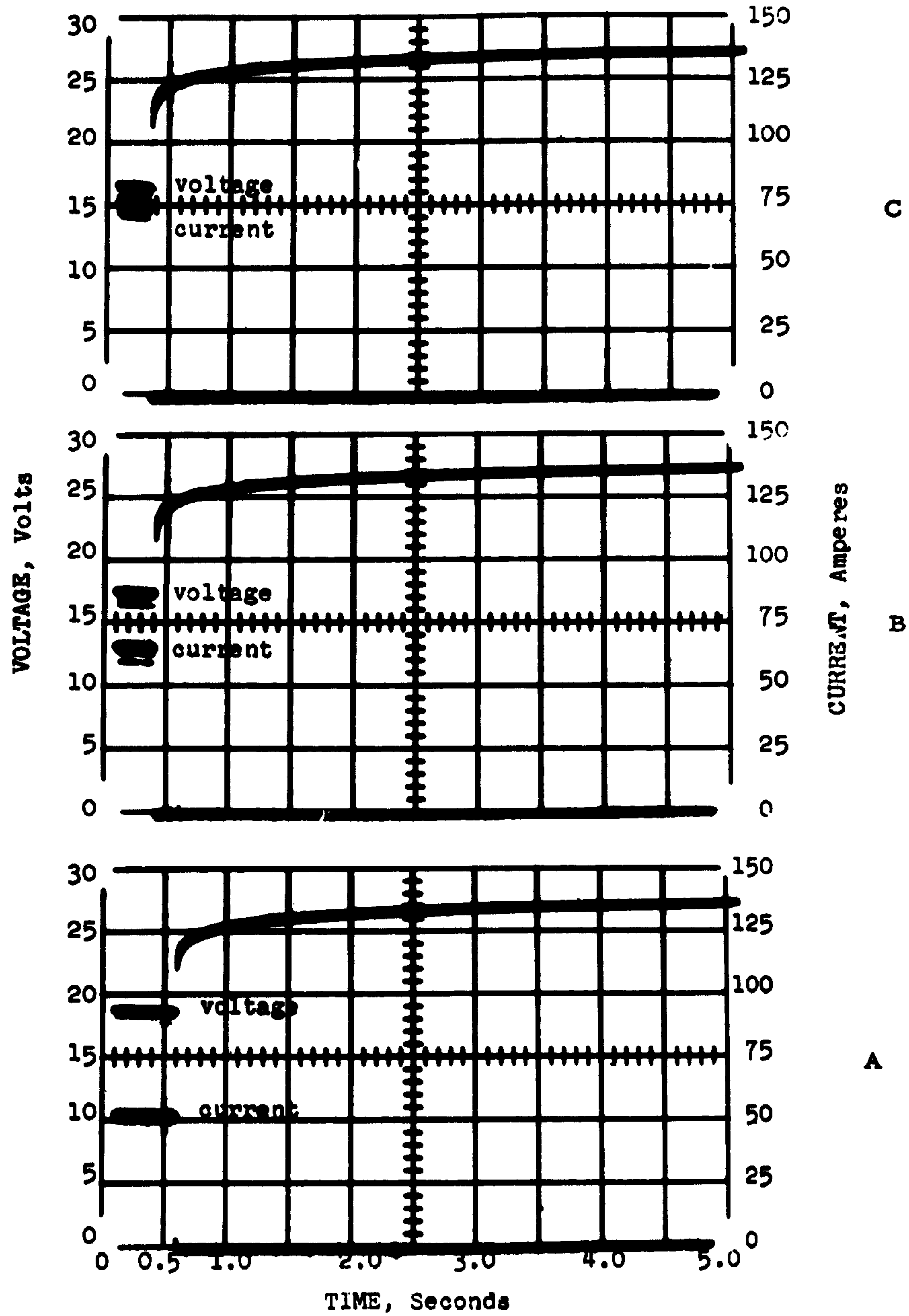
FIG. 11



DOFL Two Modules Operating - Load Removed

Figure 12

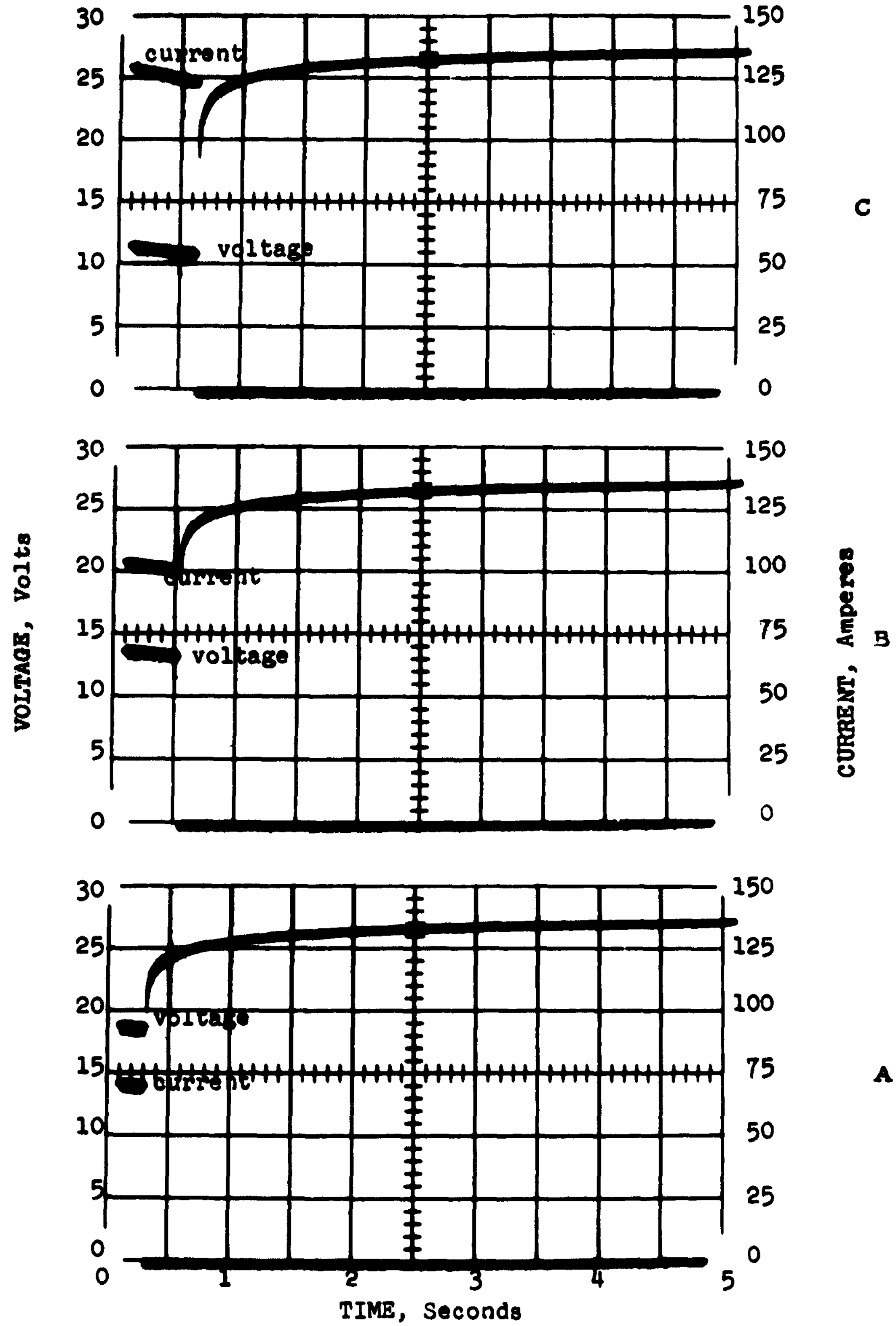
TRANSIENT RESPONSE



DOFL Two Modules Operating - Load Removed

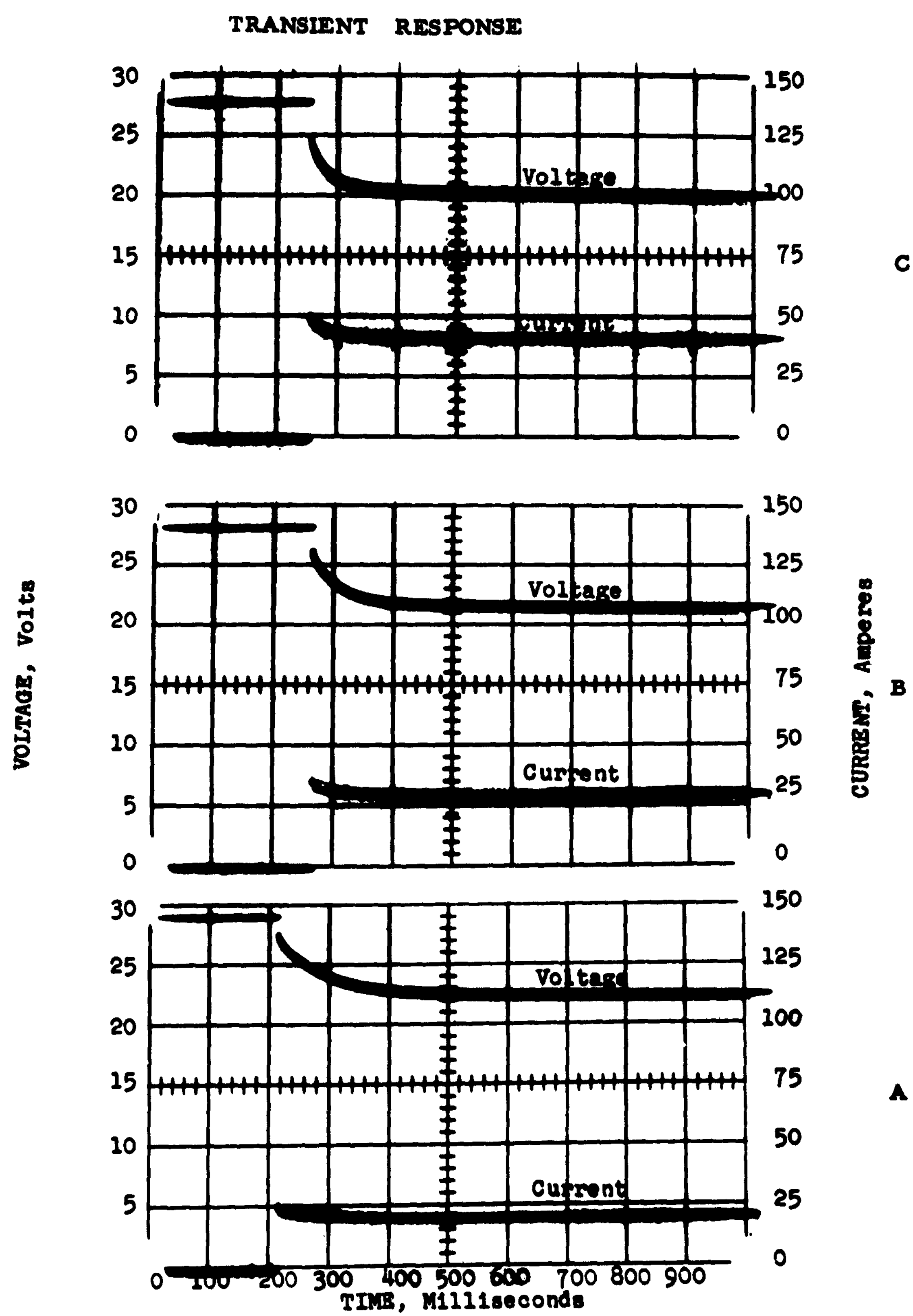
Figure 13

TRANSIENT RESPONSE



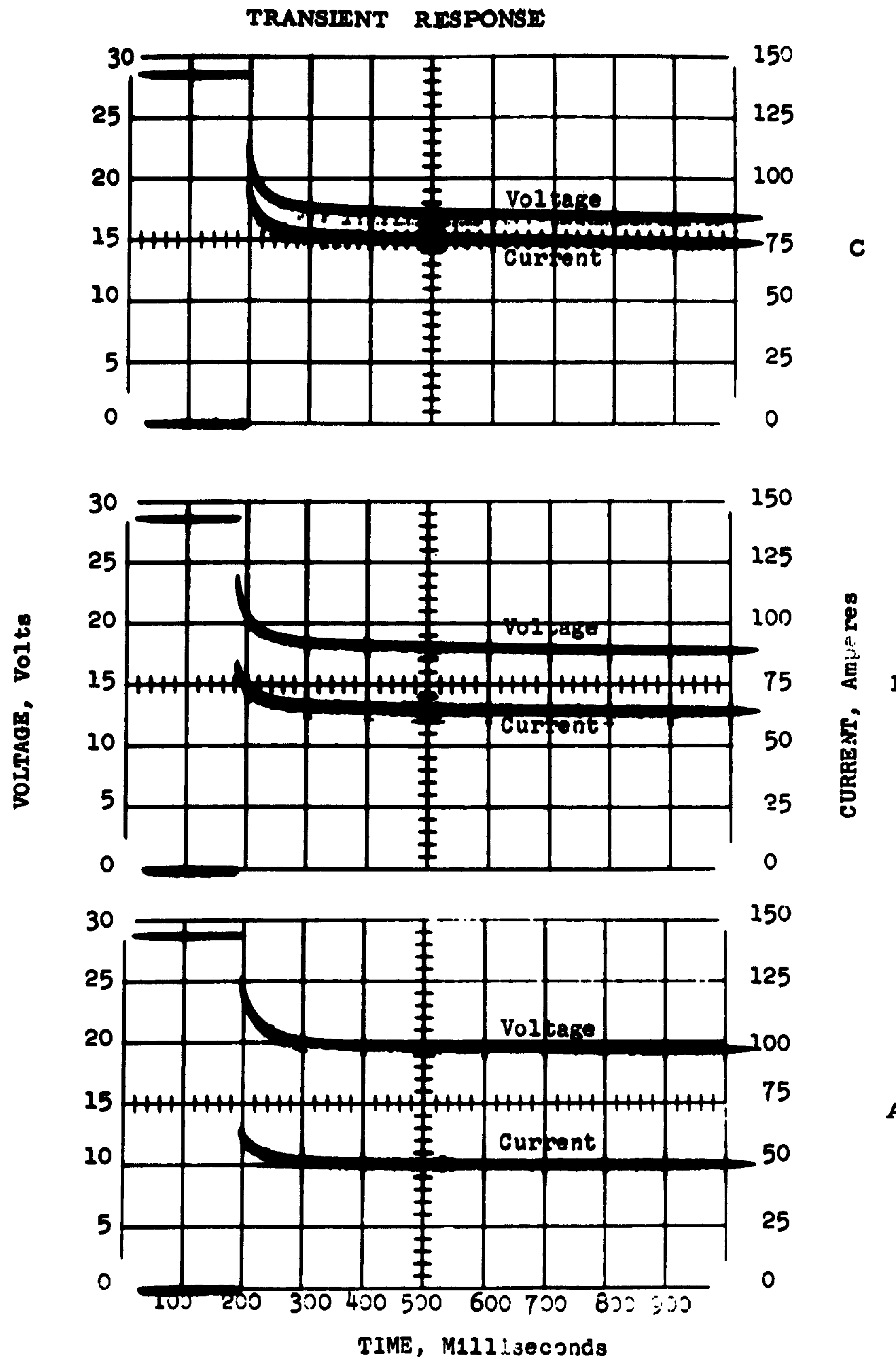
DOFL Two Modules Operating - Load Removed

Figure 14



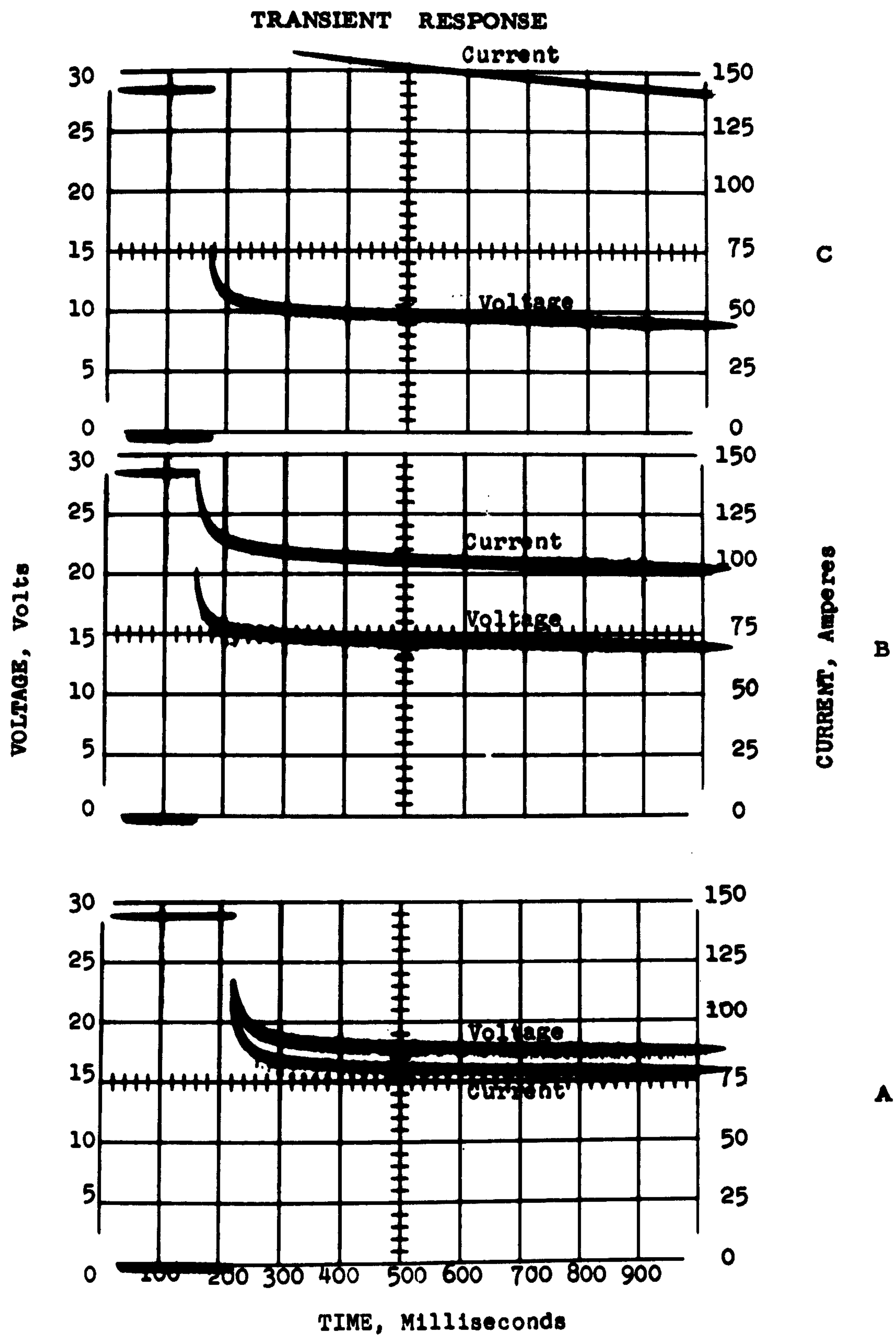
DOFL Two Modules Operating - Load Applied

Figure 15



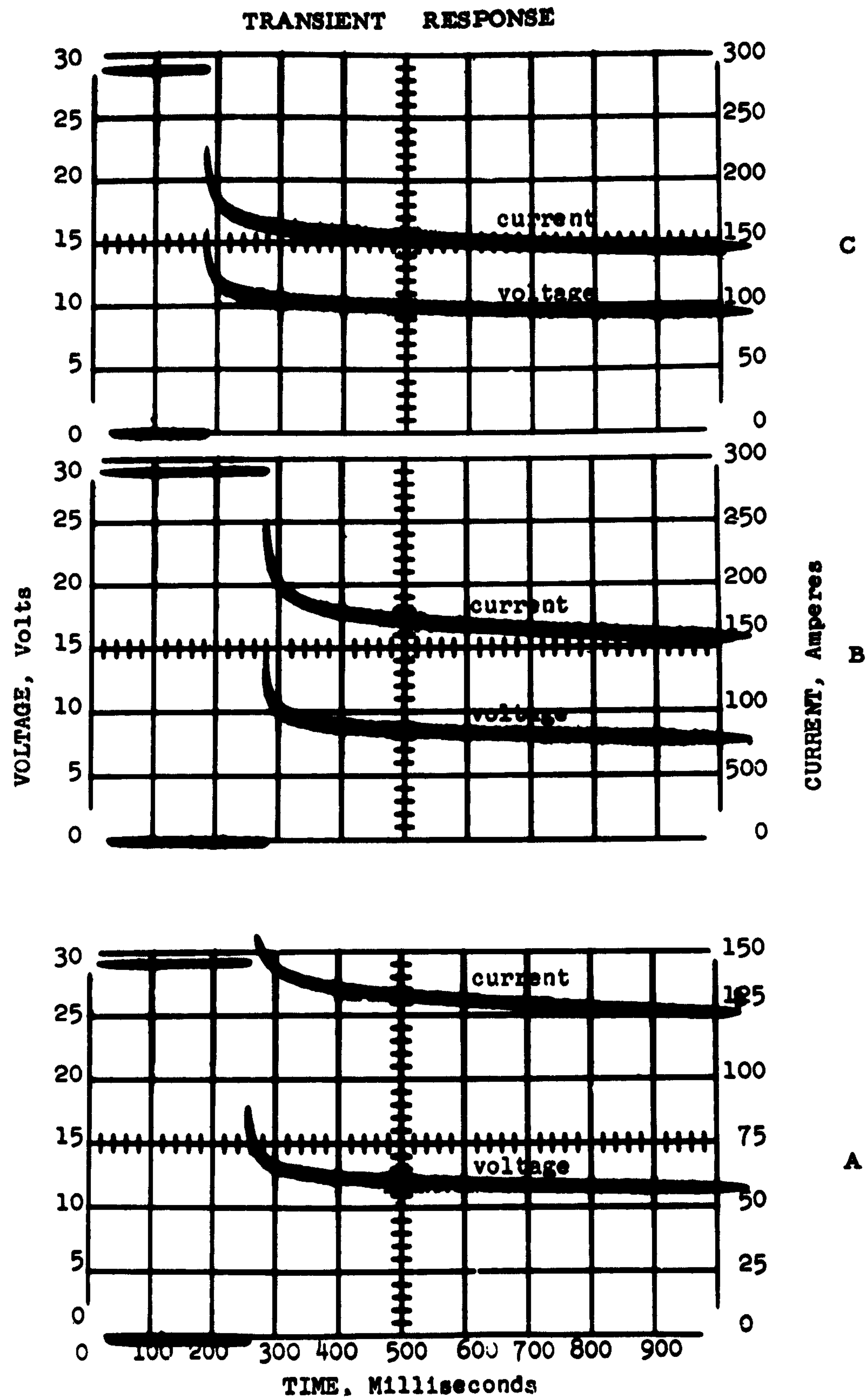
DOFL Two Modules Operating - Load Applied

Figure 16



DOFL Two Modules Operating - Load Applied

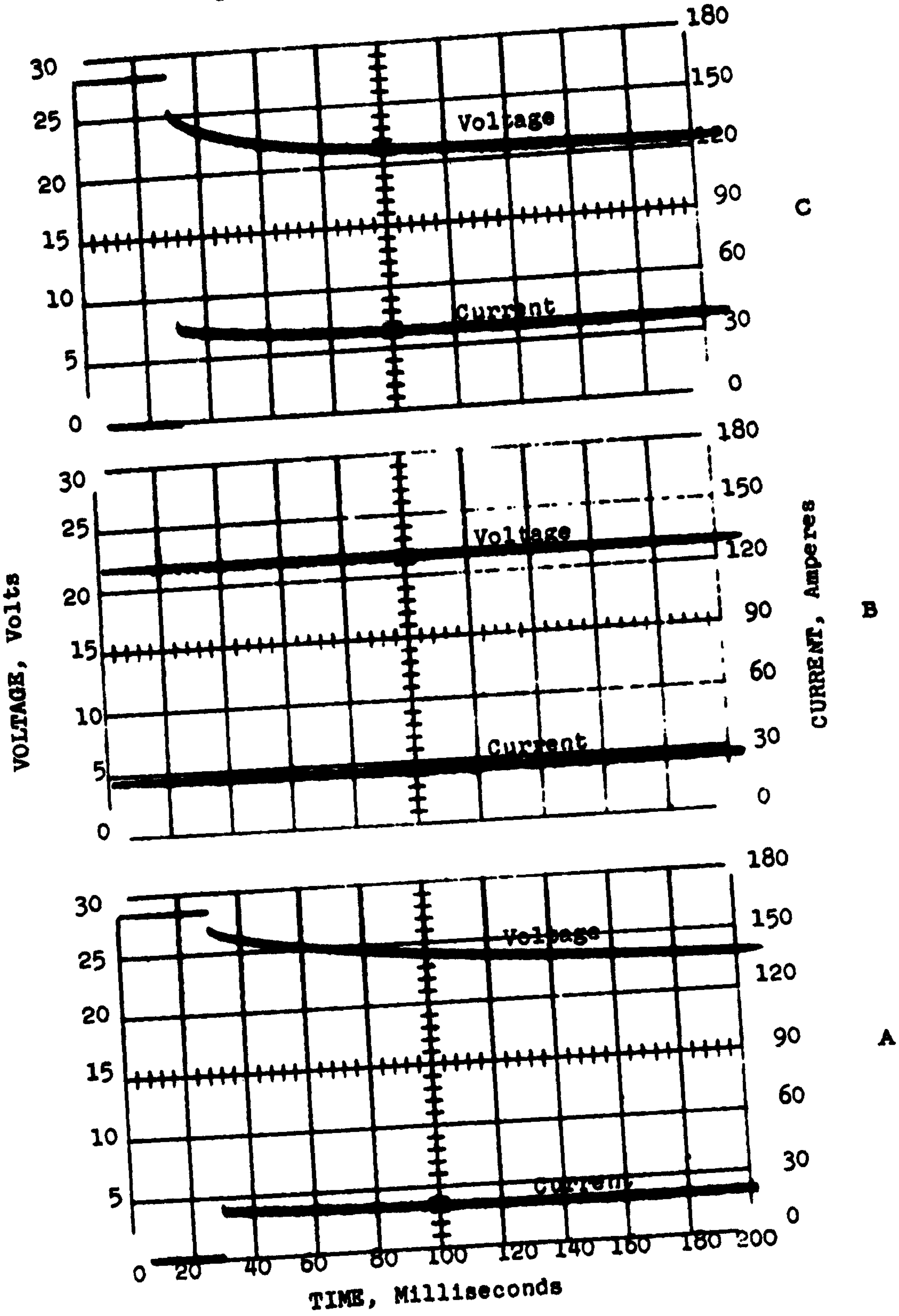
Figure 17



DOFL Two Modules Operating - Load Applied

Figure 18

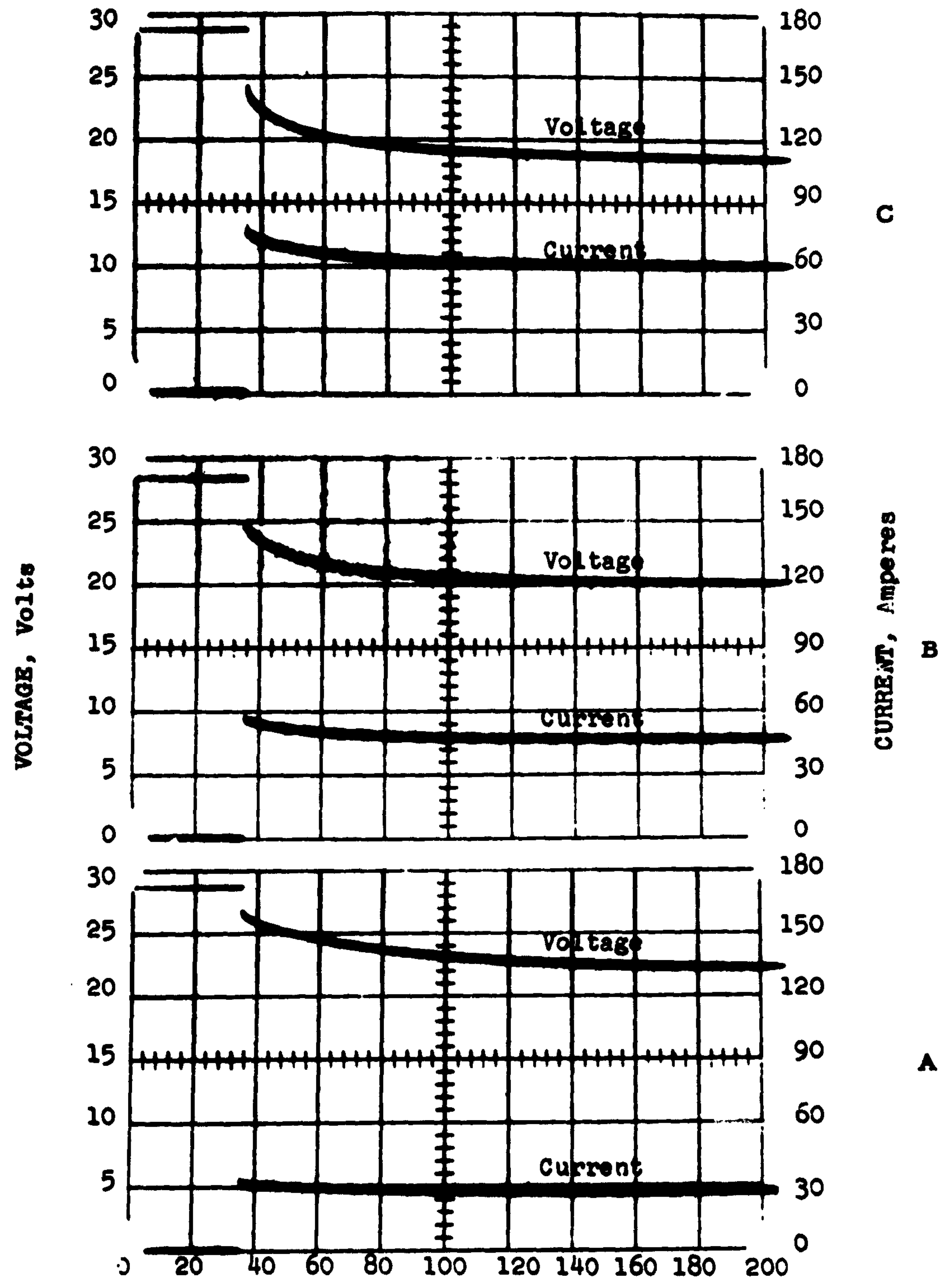
TRANSIENT RESPONSE



DOFL Two Modules Operating - Load Applied

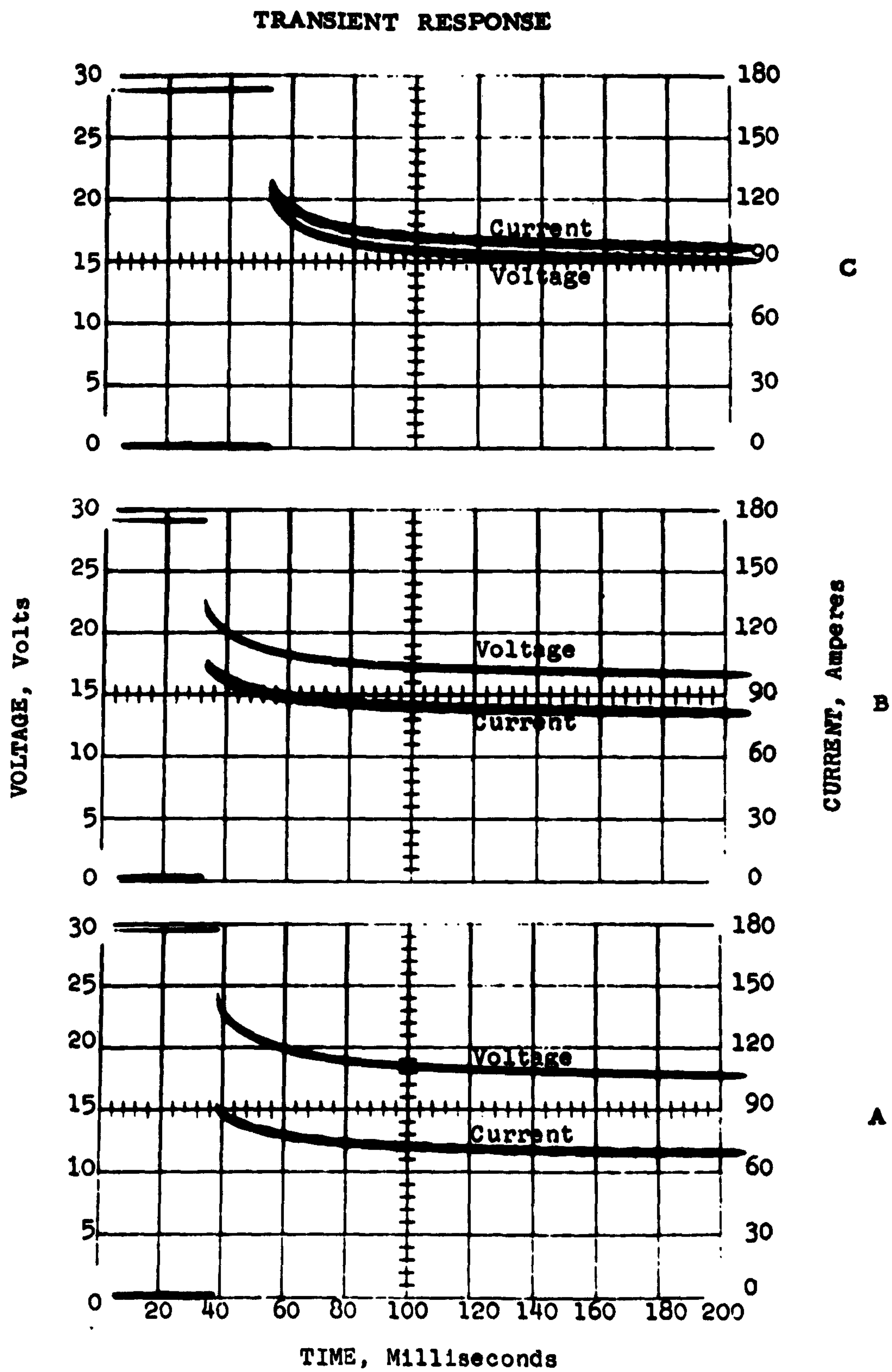
Figure 19

TRANSIENT RESPONSE



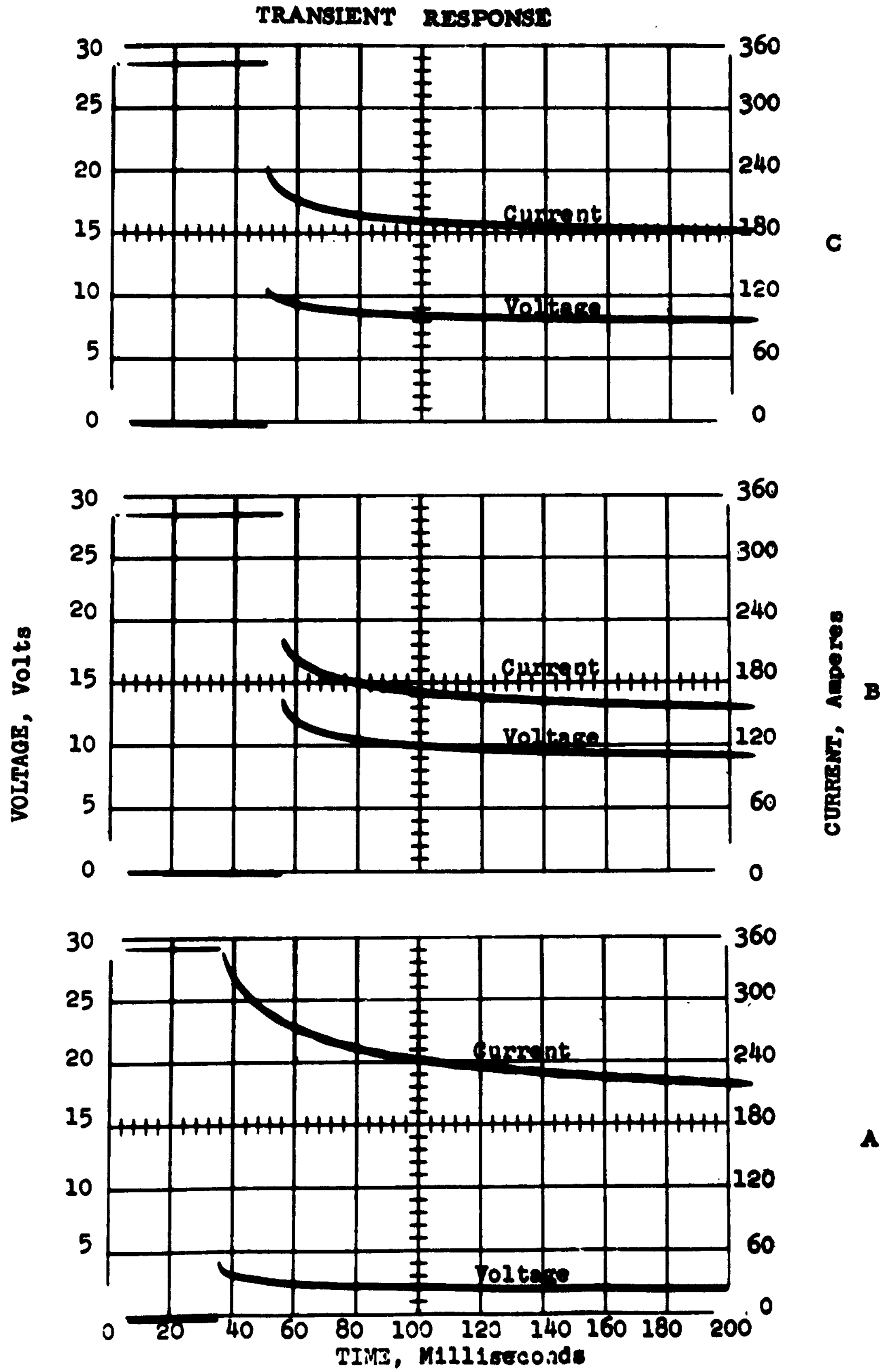
DOFL Two Modules Operating - Load Applied

Figure 20



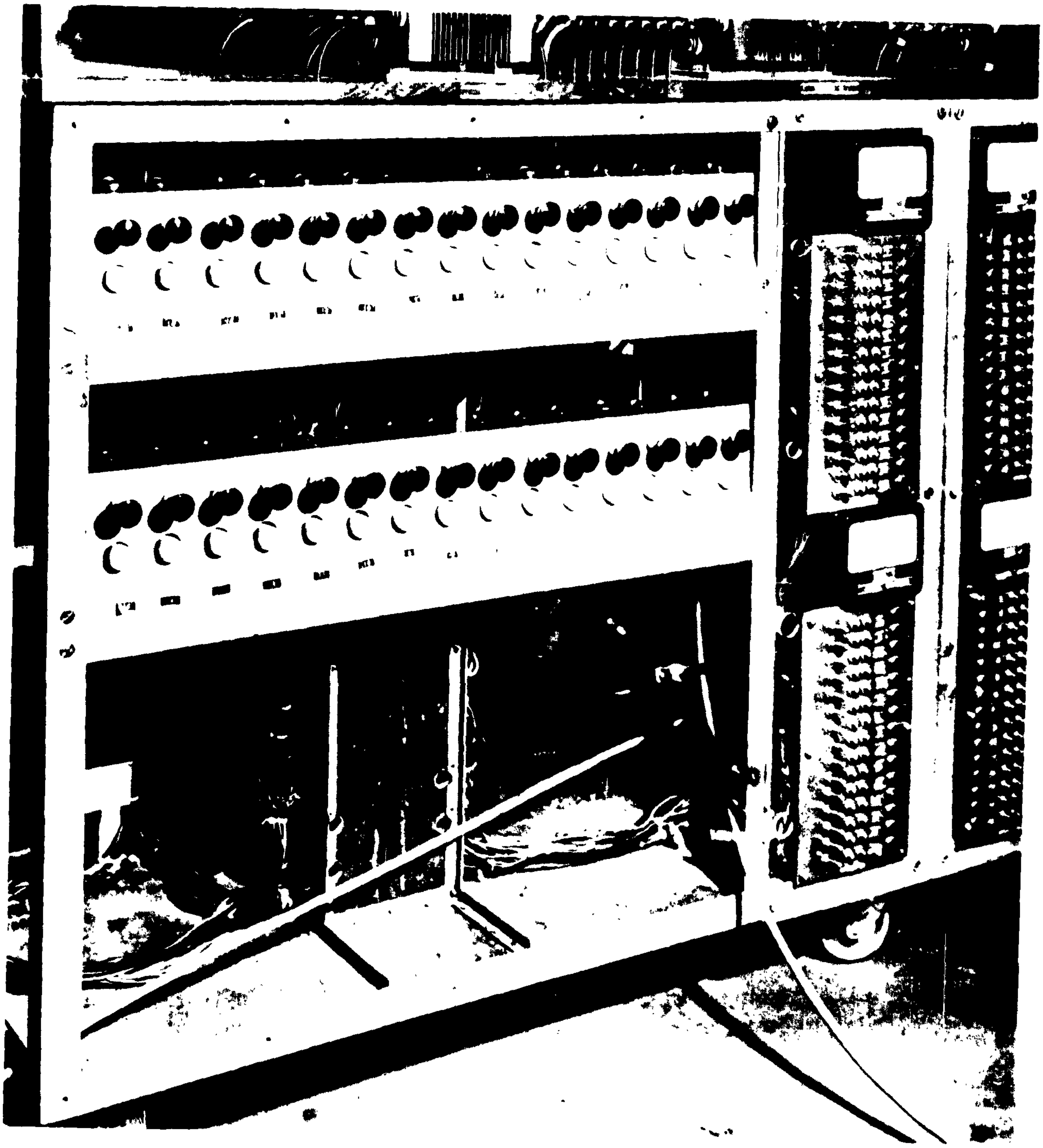
DOFL Two Modules Operating - Load Applied

Figure 21

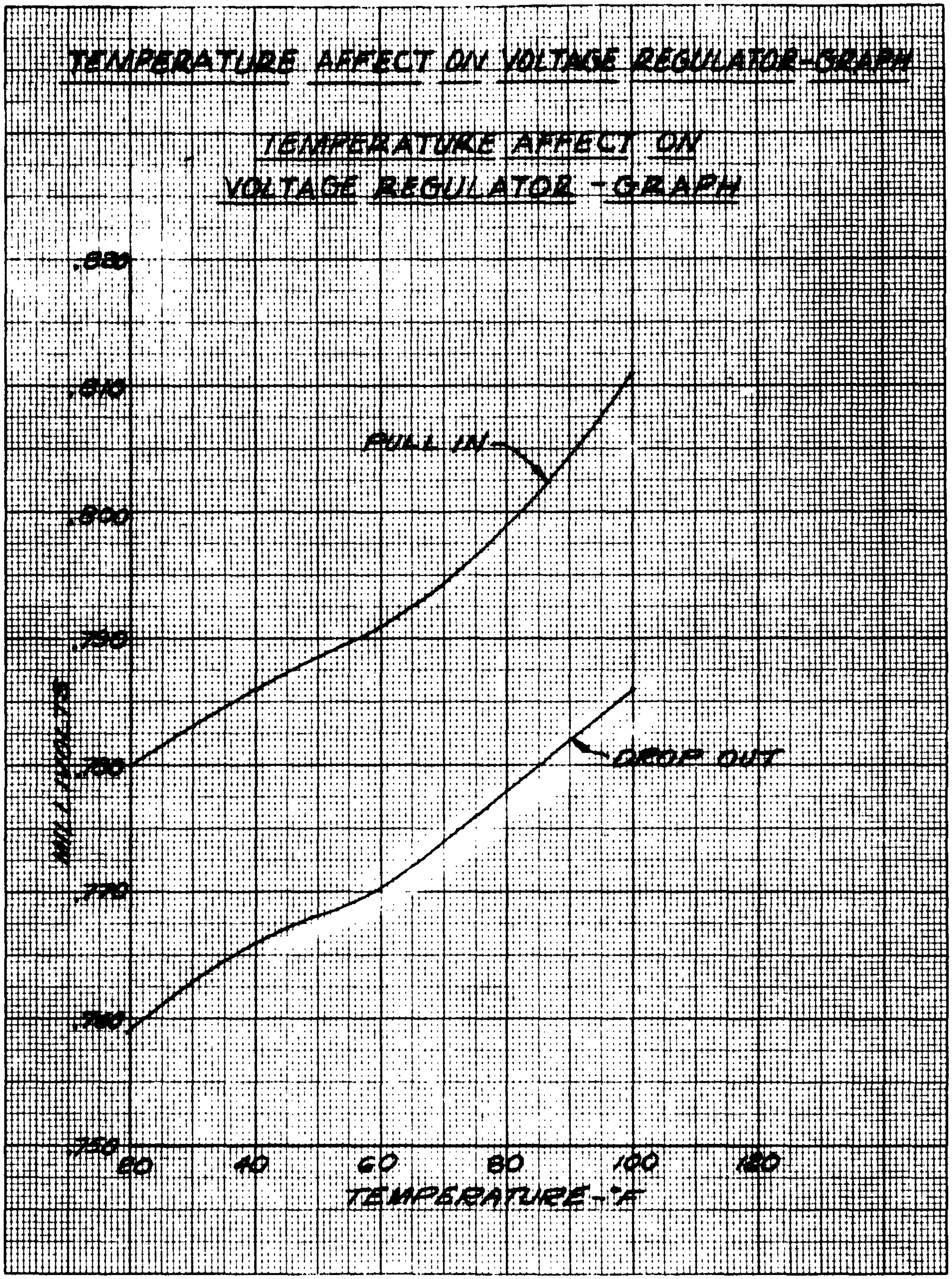


DOFL Two Modules Operating - Load Applied

Figure 22



DOFL modifies hydrogen exhaust valving system.
Fig. 23



60A S.A.D.S.
ALLIS-CHALMERS MFG. CO. FIG. 24 2-5-63 J.H.

VOLTAGE - MOISTURE CHARACTERISTICS AT CONSTANT CURRENT DENSITY HYDROGEN - OXYGEN FUEL CELL

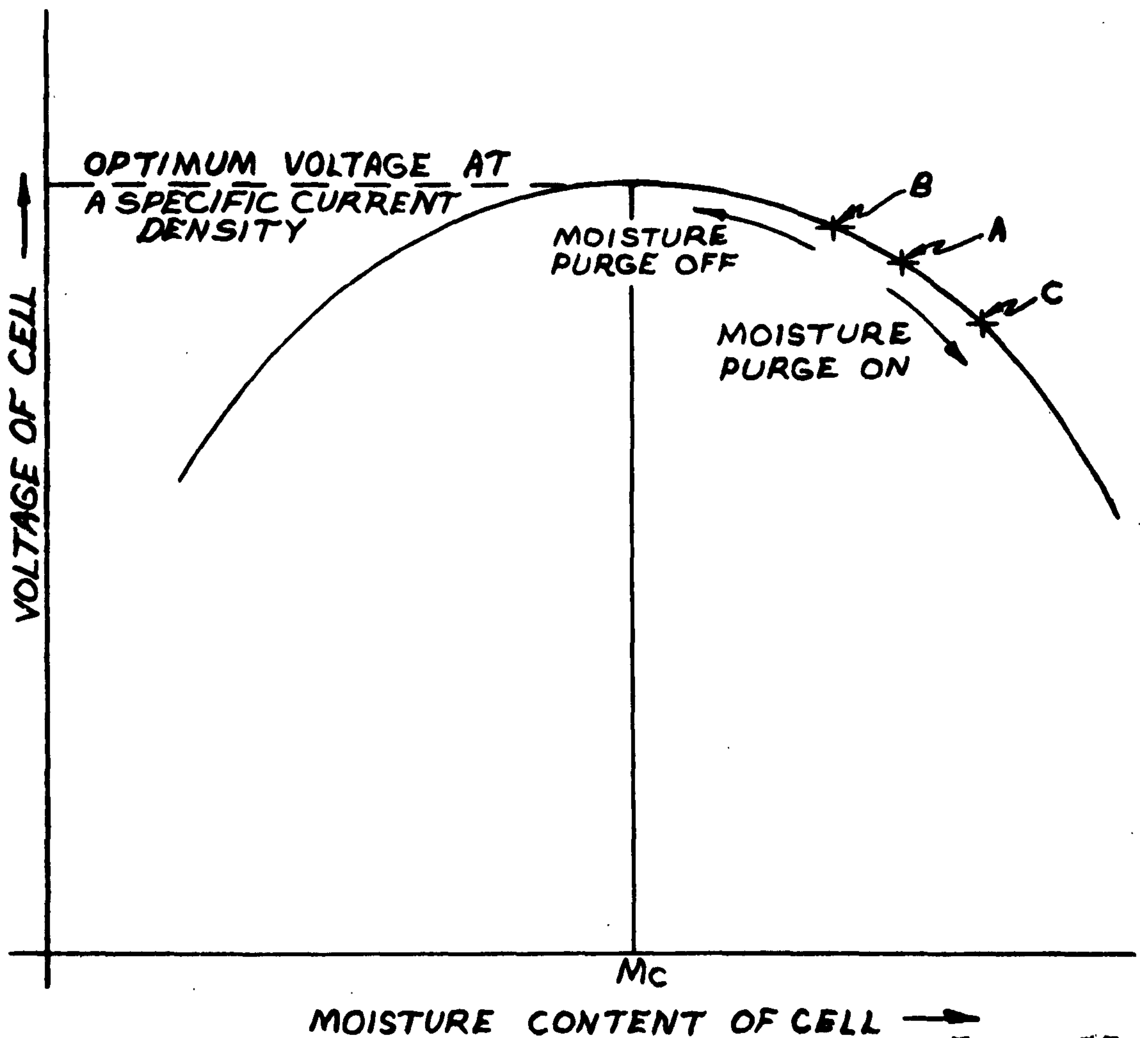
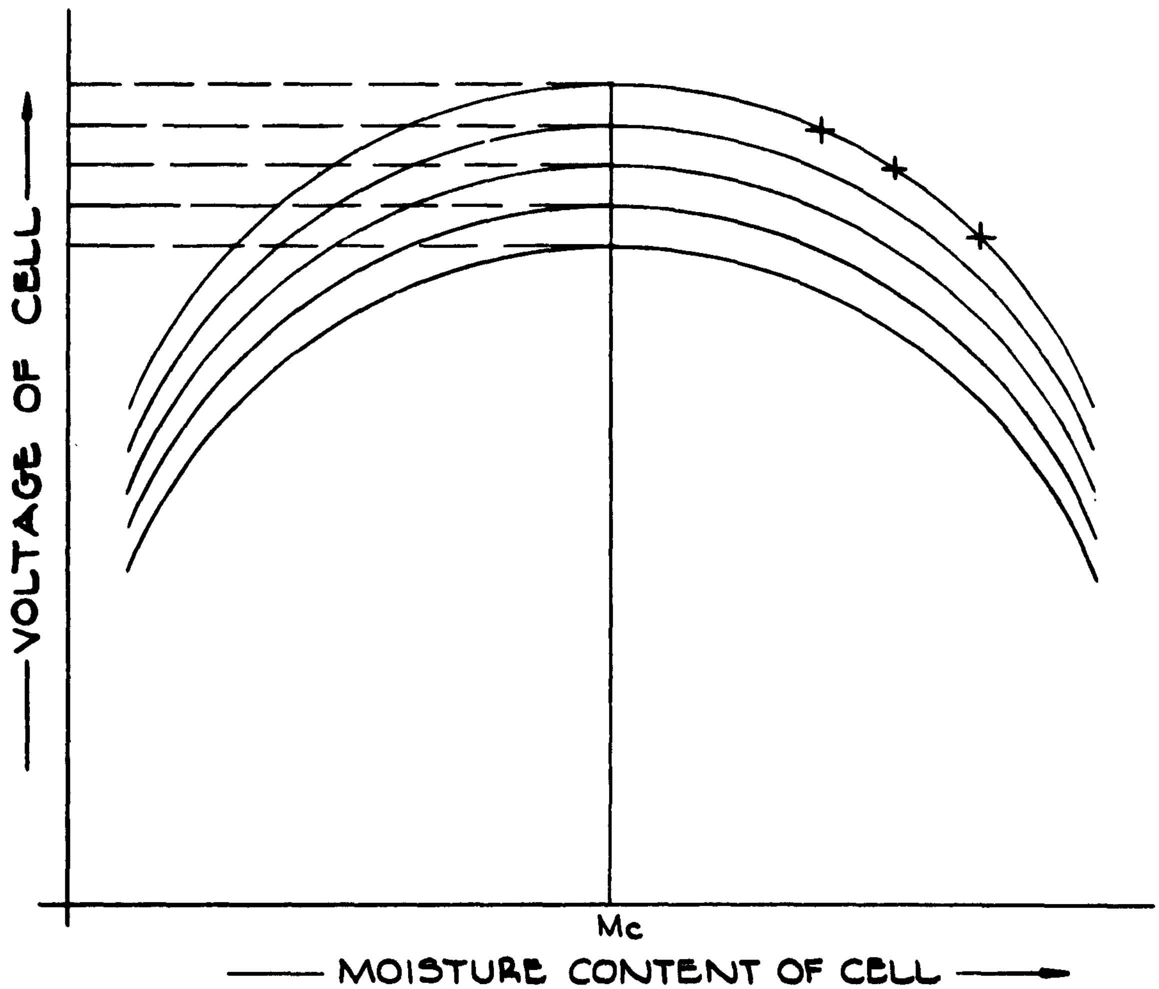


FIG. Nº [illegible]

01	7-11-67	DIMENSIONS IN INCHES SCALE ______ =1 TOLERANCES ON MACHINED DIMENSIONS UNLESS OTHERWISE NOTED: UP TO 6 INCL. ± 1/64 OVER 6 ± 1/32	DR'N ELP TR'D CH'D APP'D SIMILAR TO:	VOLTAGE MOISTURE CHARACTERISTICS HYDROGEN-OXYGEN FUEL CELL
		S.A.D.S. RESEARCH		49-100-075 01

A-C MFG. CO., MILWAUKEE, WISC.

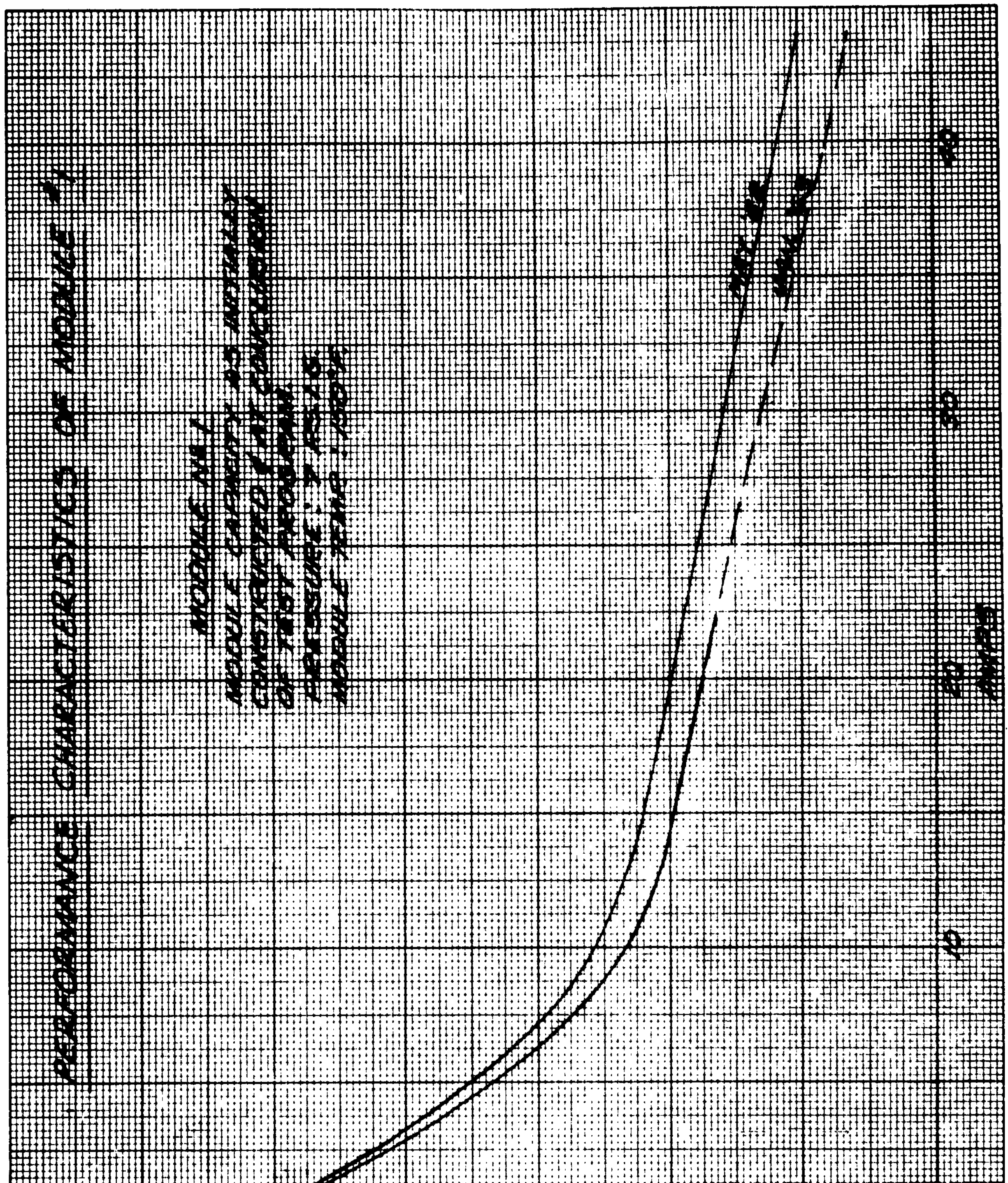
VOLTAGE - MOISTURE CHARACTERISTICS HYDROGEN-OXYGEN FUEL CELL



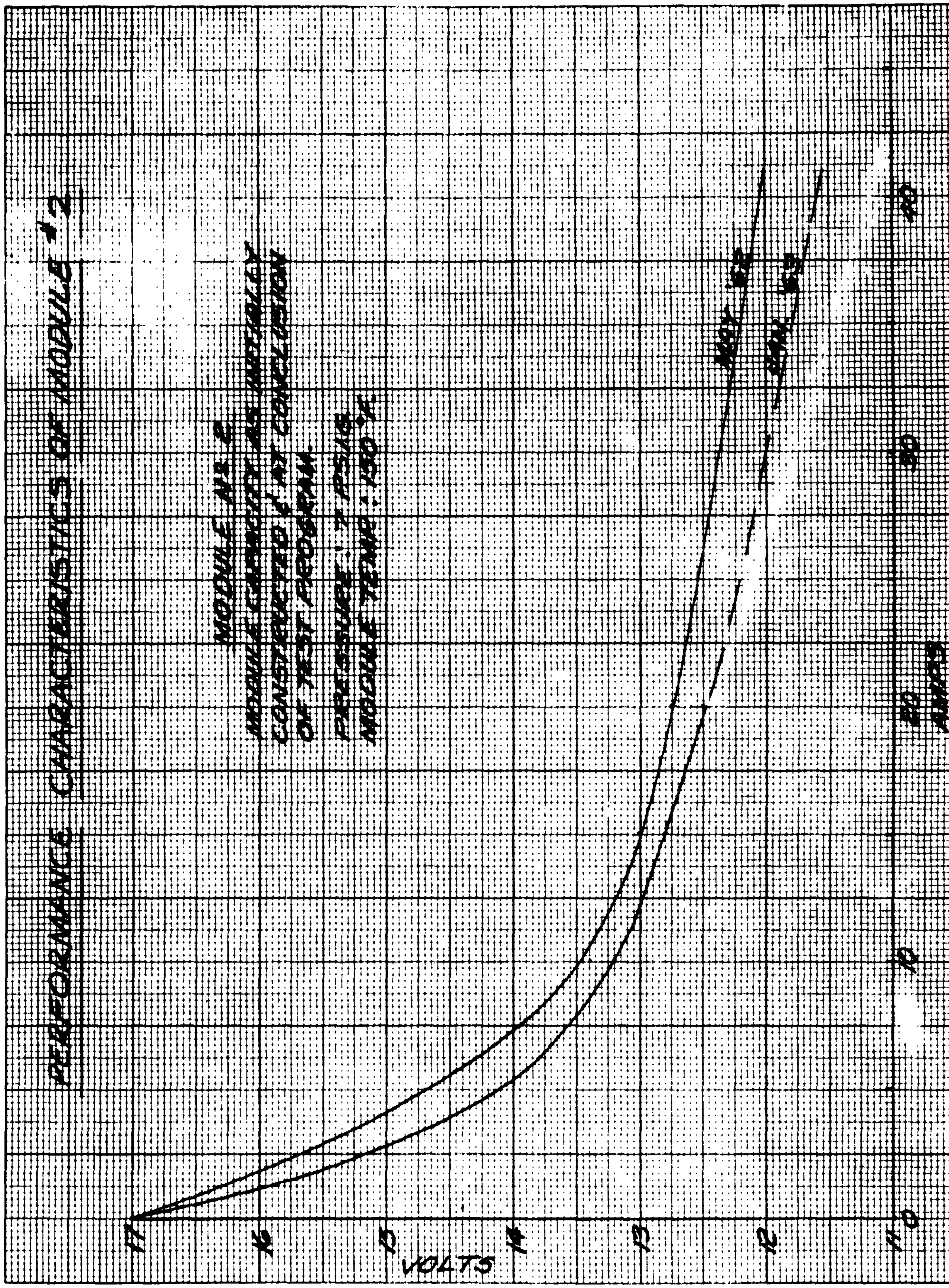
ALLIS-CHALMERS MFG. CO.
SADS- RESEARCH - PLB

FIGURE 26

13K63039-1



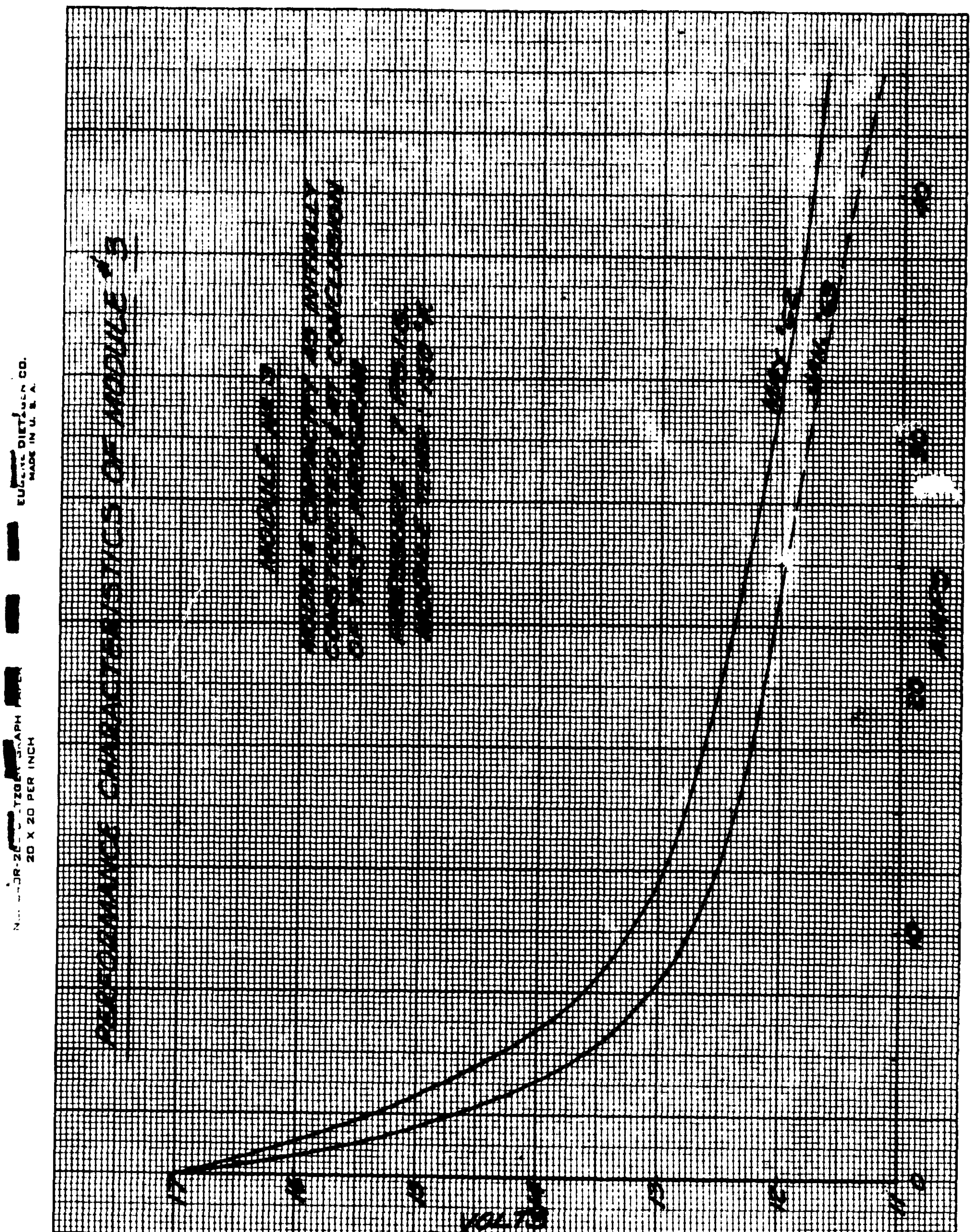
S.A.D.S.
ALLIS-CHALMERS MFG. CO.   FIG. 27   2-7-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 28

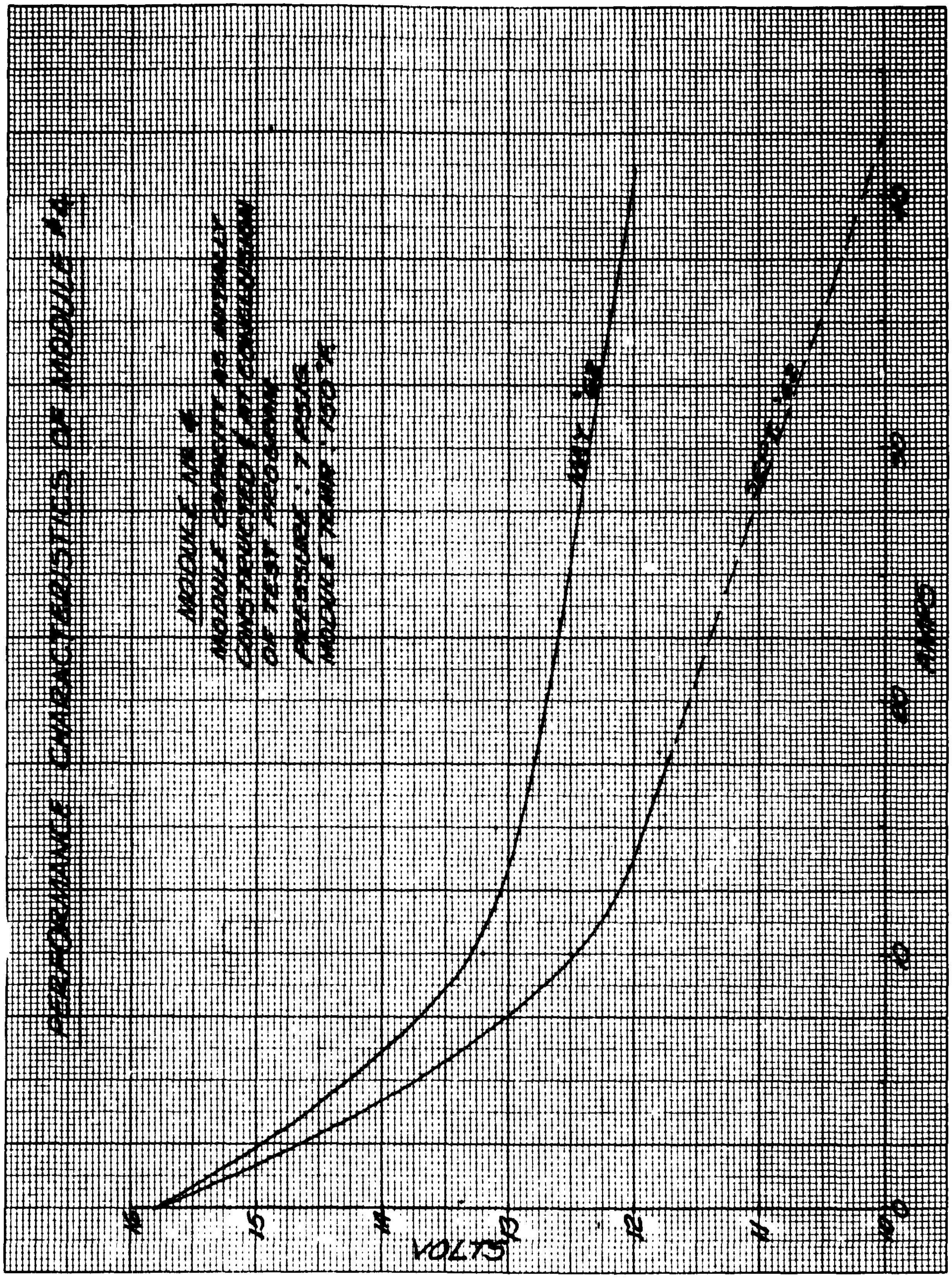
2-7-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG.CO.

FIG. 29

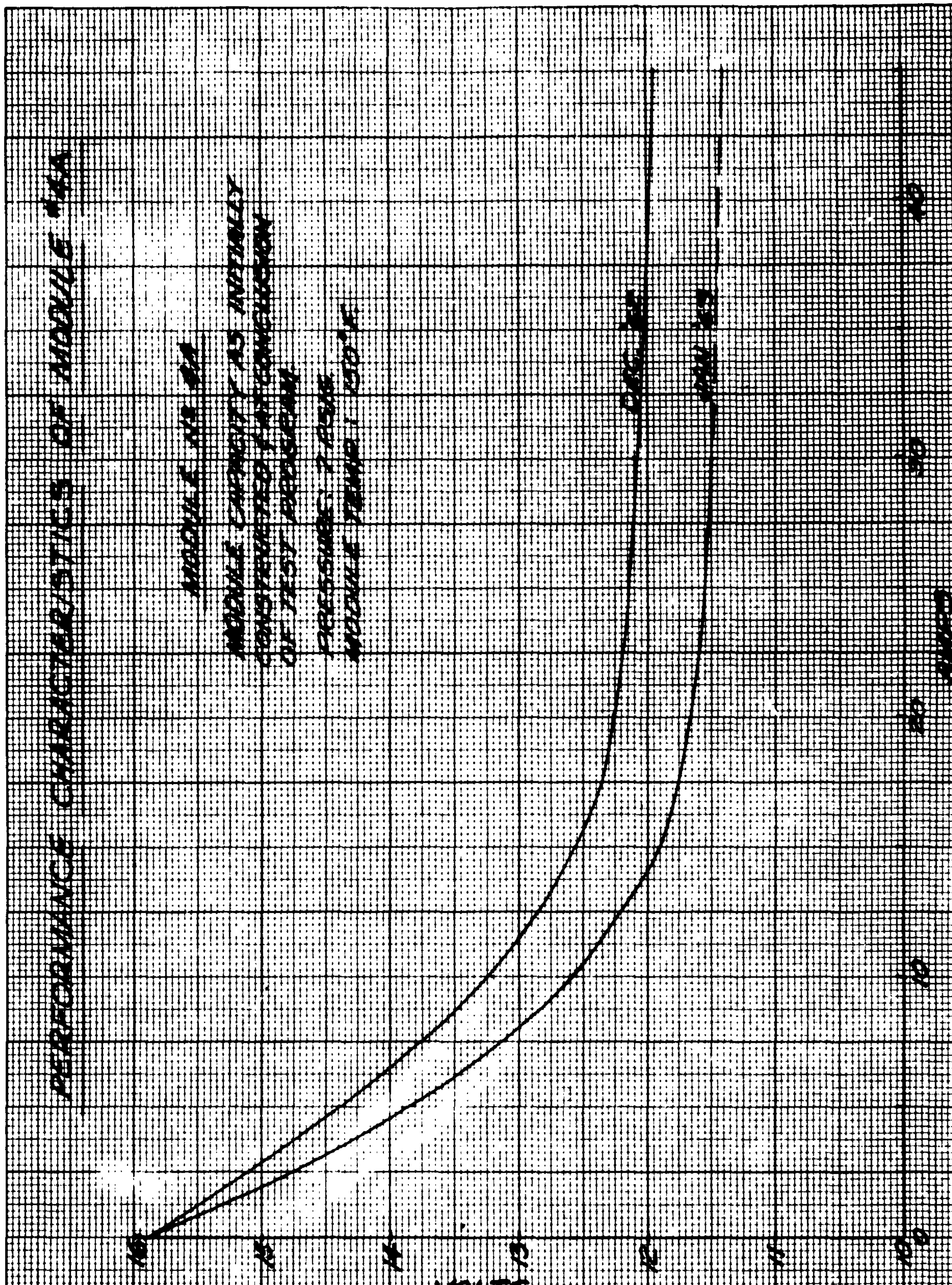
2-7-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 30

2-7-63 J.H.



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 31

2-7-63 J.H.

FIGURE 32

Run No. 48 15 Amps

4 Modules

75° F

Amperes	Time in Hrs.	Amp-Hr.
10	1.25	12.5
14	0.5	7.0
15	5	75
	6.75 hrs	94.5 a-h

Avg Voltage 49.03 volts

Fuel Consumed 749 ft^3 of H_2
63.4

$$g = \frac{Mpv}{RT}$$

21.7 psi = 1121/760 mm Hg

$$\frac{63.4\ ft^3}{35.3144\ \frac{ft^3}{m^3}} = 1{,}795 \text{ liters}$$

$$= \frac{(2)\left(\frac{1121}{760}\right)(1{,}795)}{(0.08205)(295.1)}$$

$$R = 0.08205 \ \frac{\text{liter atom}}{{}^\circ\ \text{Mole}}$$

$$T = 273.1 + 22^\circ C = 295^\circ R$$

$$= \frac{5320}{24.2}$$

$$= 219.5 \text{ g } H_2$$

$$= \frac{219.5 \text{ g}}{453.4 \text{ g/lb}} = 0.484 \text{ lbs } H_2$$

Figure 32 (continued)

Measured Current Eff. Calc.

$$N_c = \frac{\text{Elect. Eng. out (measured)}}{\text{Theor. Eng. Content of Fuel Cons. (measured)}} \times 100\%$$

$$E_F \text{ out} = (94.5 \ \frac{A - h}{cell}) \quad (60 \text{ cells})$$

$$= 5670.0 \ A - hr$$

$$E_F \text{ in} = \frac{219.5 \ g \ H_2}{0.0376 \ \frac{g \ H_2}{A - hr}}$$

$$N_c = \frac{5670}{5840} \times 100\% = 97.2\ \%$$

Measured Fuel Cell Efficiency

$$N_{FC} = \frac{(V)\ (A)\ (hr)}{(14,900 \ \frac{w - hr}{lb})\ (lb\ H_2)} \times 100\%$$

$$= \frac{(49.03)(94.5)}{(14,900)(0.484)} \times 100\% = 64.3\ \%$$

Measured Thermal Efficiency

$$N_T \quad \frac{(49.03)\ (94.5)}{(17,900)(0.484)} \times 100\% = 53.5\%$$

Figure 32 (continued)

Theoretical Fuel Cell Efficiency (assuming 100% Current eff.)

$$N_{FC} = \frac{\frac{49.03}{60}}{1.23} \times 100\% = 66.5\%$$

Theoretical Thermal Eff.

$$N_T = (66.5)\left(\frac{14.9}{17.9}\right) = 55.4\%$$

System Efficiency for this run

As measured:

$$N_s = \frac{\text{Net power, out of system}}{\text{Gross power produced by cells}} \times 100\%$$

$$= \frac{(49.03 \text{ volts})(15 \text{ amps}) - 492 \text{ watts}}{(49.03)\ (15)} \times 100\%$$

$$= \frac{736 - 492}{736} \times 100\%$$

$$= \frac{244}{736} \times 100\% = 33.1\%$$

Material and Current Efficiency Calculation for combined runs on Table 1

(All values from Table 1)

Measured amps hours	=	48,402 a-h
Measured H_2 in grams	=	1,845.2 g
Measured H_2O out in grams	=	16,548.0 g
Theoretical H_2O in grams (based on gas consumed)	=	16,606.5 g

Figure 32 (continued)

Measured Current Efficiency Calculation

out $\quad E_F = 48{,}401.6$ amp hours measured out

in $\quad E_F = \dfrac{1{,}845.6 \text{ g } H_2}{.0376 \text{ g of } H_2/\text{amp hr}}$

$= 49{,}069$ a-h

$$N_C = \frac{48{,}401.6}{49{,}069.0} \times 100\% = 98.63\%$$

Materials Balance for the combined test series.

9 (measured H_2) = H_2O collected

9 (1,845.2 g) = 16,606.8 g H_2O

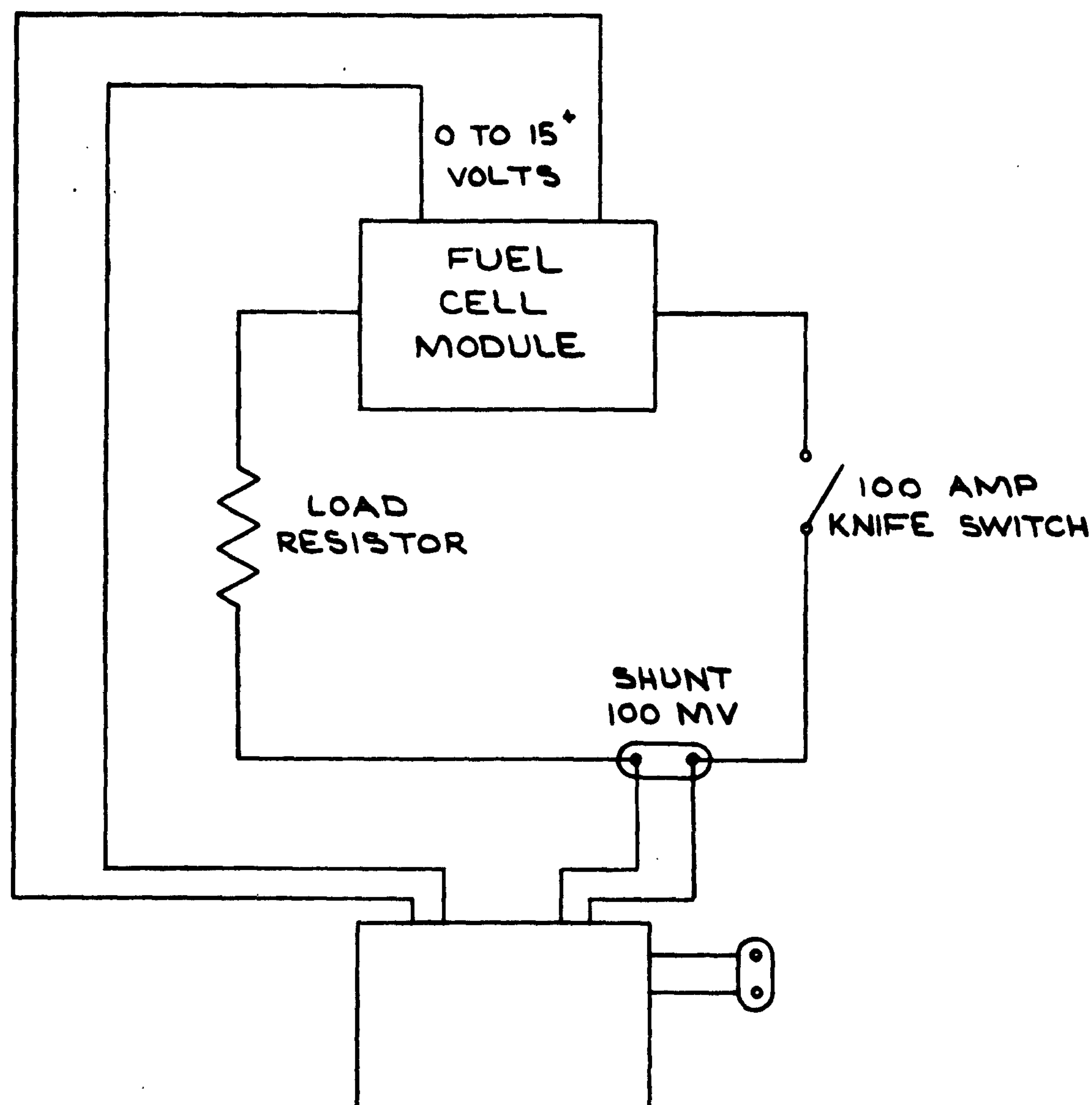
theoretical - actual =

16,606.8 - 16,548.0 = 58.8 g H_2O

$$\frac{58.8 \text{ g}}{16{,}548.0 \text{ g}} \times 100\% = .45\%$$

There is a .45% deviation between the measured material in and the measured material out of the fuel cell system.

ELECTRICAL WIRING DIAGRAM UTILIZING AN OSCILLOSCOPE

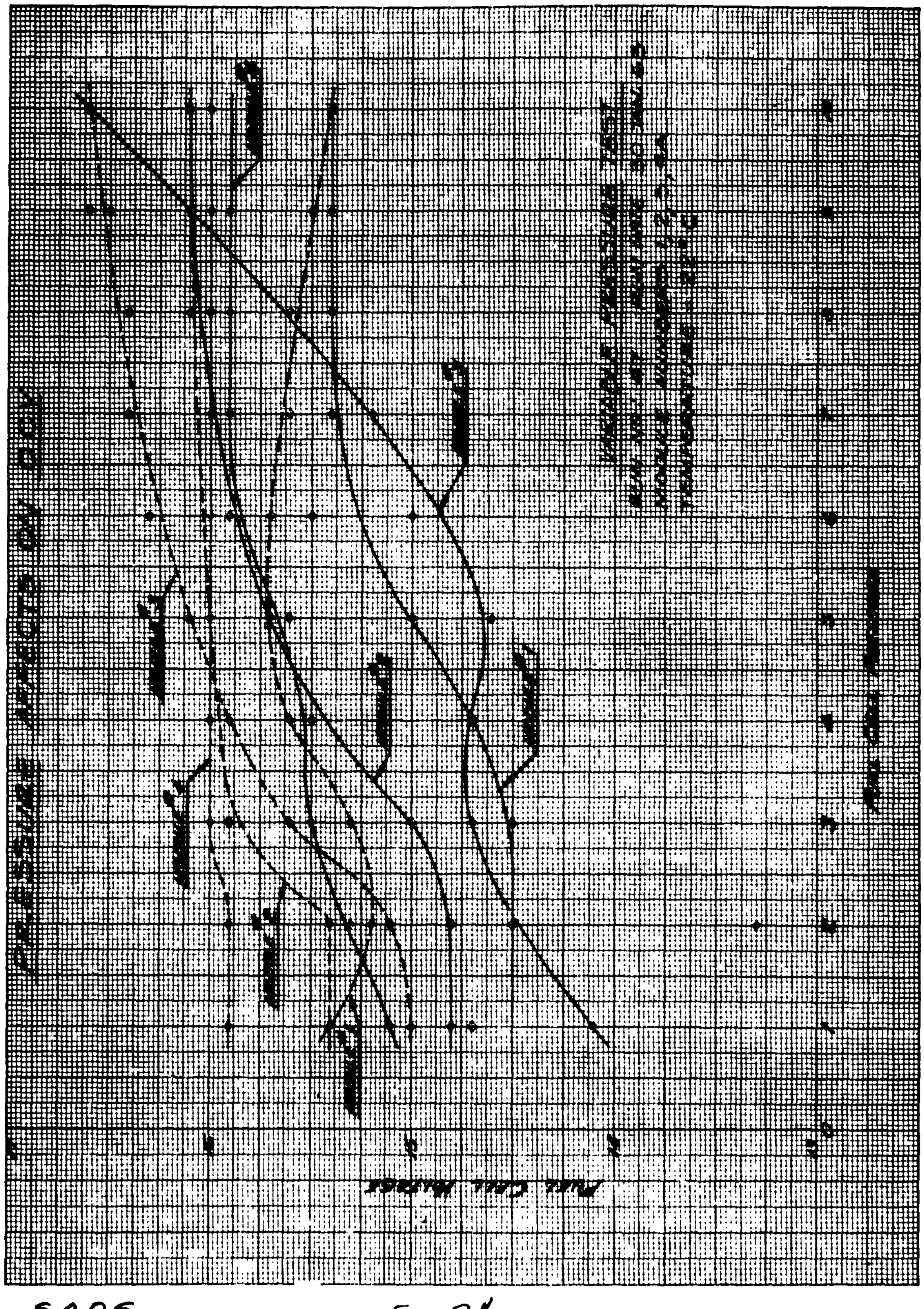


MODEL 535 TEKTRONIX OSCILLOSCOPE
& DUMONT OSCILLOSCOPE CAMERA WITH
MODEL # 53/54C PLUG IN PREAMPLIFIER.

FIG. 33

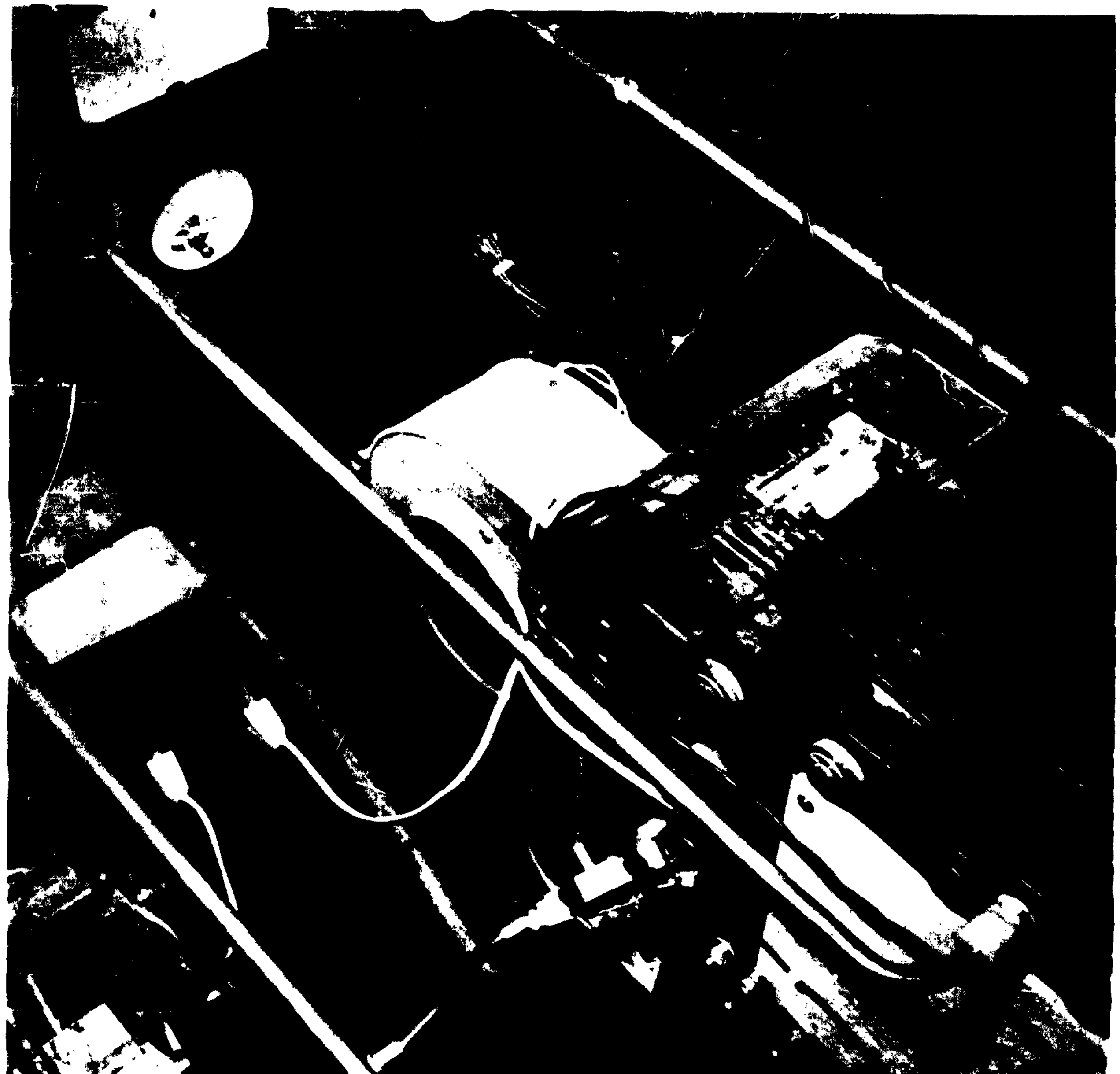
ALLIS-CHALMERS MFG. CO.

SK 63028-1
T.F.E. 1-28-63



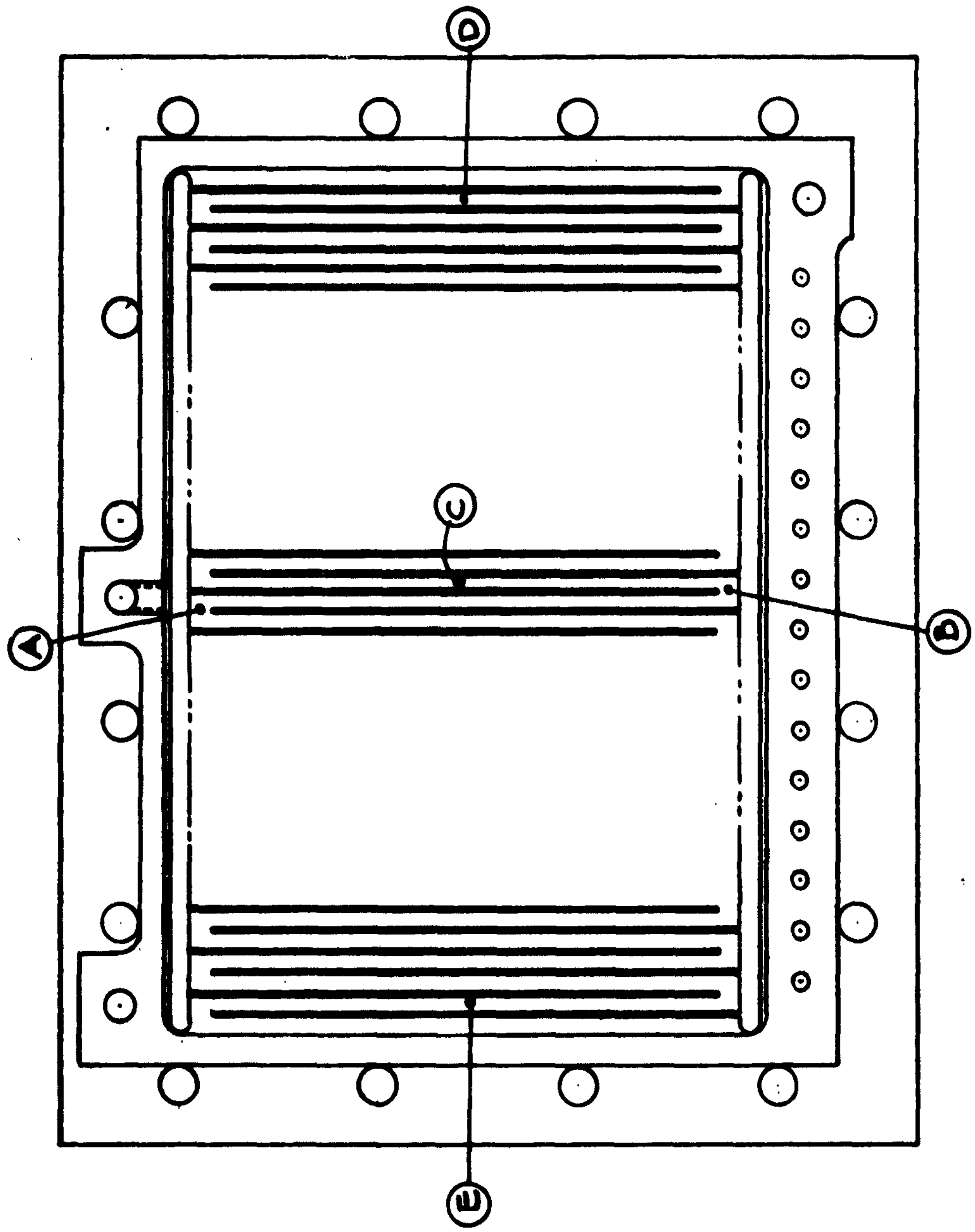
S.A.D.S.
ALLIS-CHALMERS MFG.CO. Fig 34

2-12-63



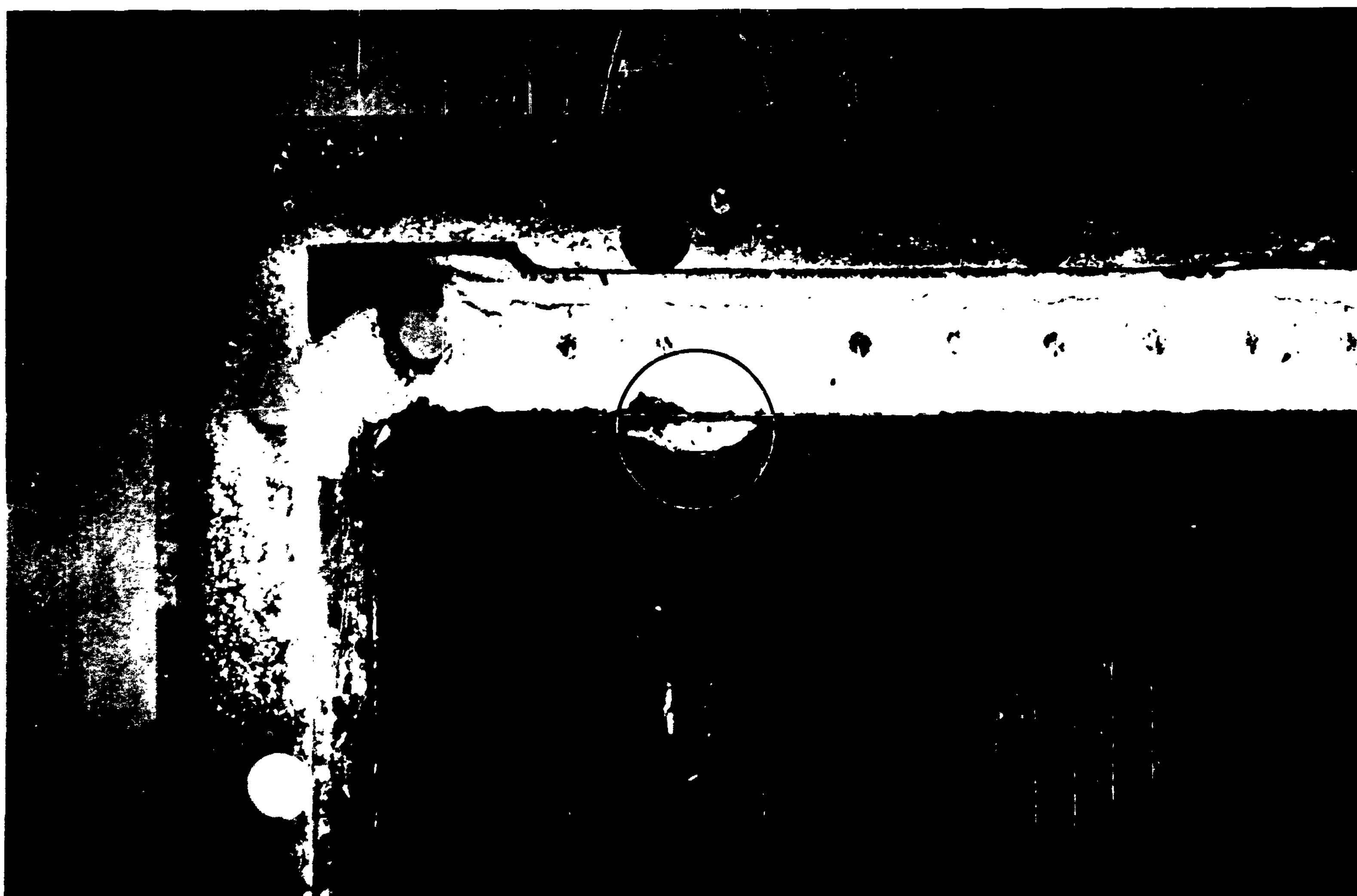
ALLIS-CHALMERS

DOFL air-cooling system for module.
Fig. 35



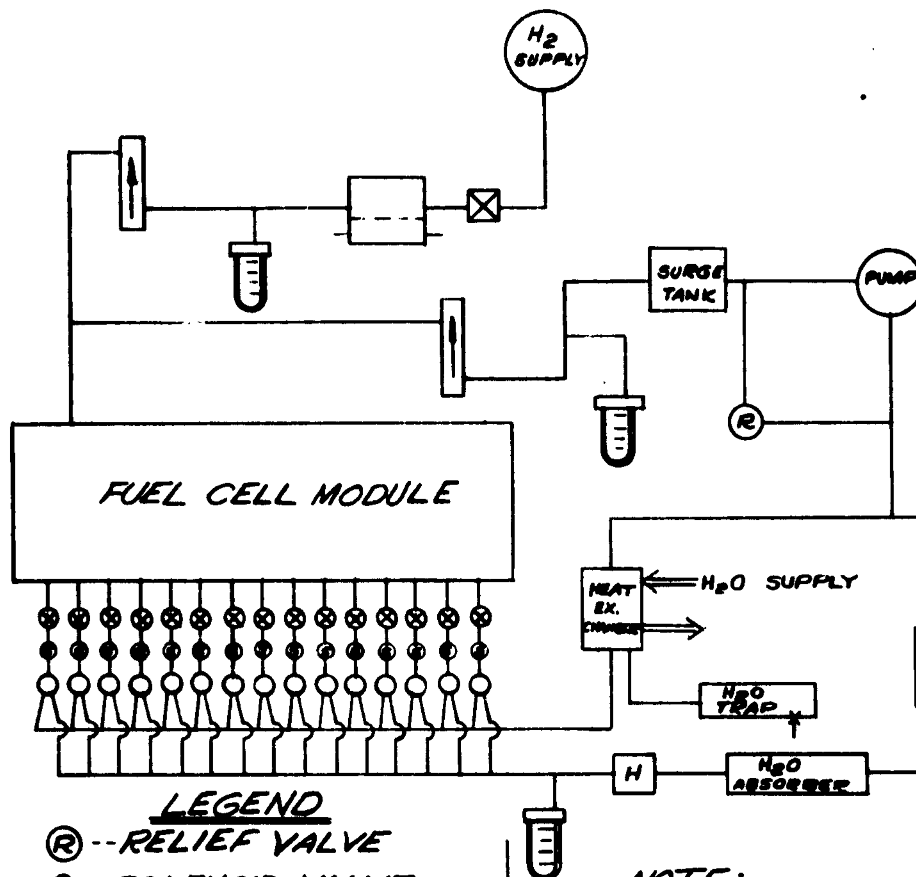
THERMOCOUPLE LOCATION ON BI-POLAR PLATE

FIG. 36



ALLIS-CHALMERS

DOFL wax obstruction in H_2 manifold.
Fig. 37



LEGEND

- R --RELIEF VALVE
- ● --SOLENOID VALVE
- ⊗ --THROTTLE VALVE
- ⊠ --SHUT-OFF VALVE
- --DIFFERENTIAL PRESSURE REGULATOR
- --MANOMETER
- H --HUMIDITY SENSOR
- --ROTAMETER
- --THREE-WAY VALVE

NOTE:
ONLY ONE MODULE SHOWN FOR SIMPLICITY

2-4800-00001

DIMENSIONS IN INCHES
SCALE NONE
TOLERANCES ON MACHINED DIMENSIONS UNLESS OTHERWISE NOTED:
UP TO 6 INCL. ± 1/64
OVER 6 ± 1/32

DR'N	10-8-62	J.H.
TR'D		
CH'D		
APP'D		

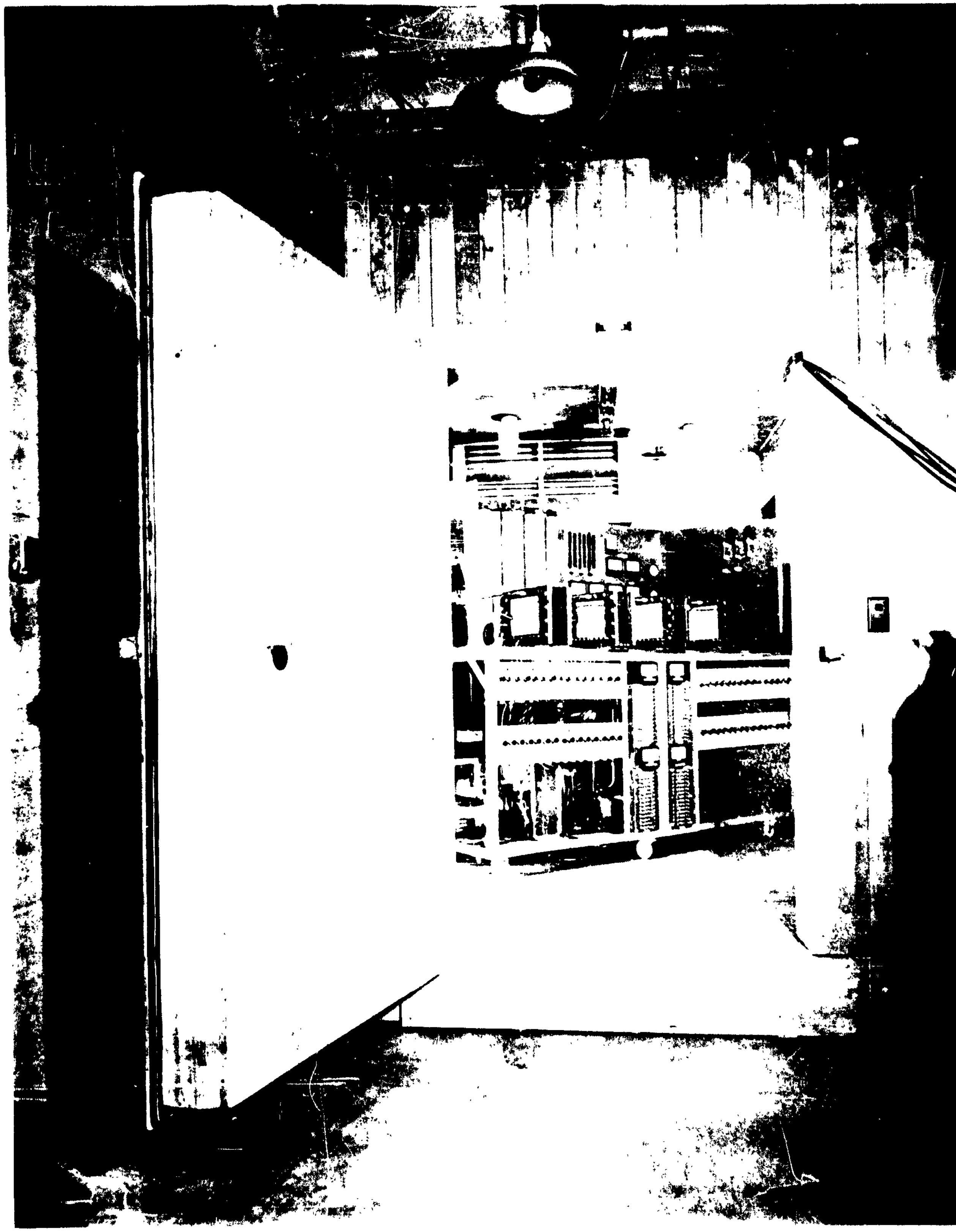
SIMILAR TO: NONE

— Confidential —
Property of ALLIS-CHALMERS MFG. CO.
S. A O.S. (RESEARCH)

REVISED RECIRCULATION SYSTEM

1-SK-62282-1

FIG. 38



ALLIS-CHALMERS

DOFL unit in envir[illegible]

Fig. [illegible]